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HANDBOOK OF EFRIGERATING ENGINEERING

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PREFACE

In view of the tremendous strides made in the low temperature it was deemed advisable to completely rewrite the text for the rd edition of the *Handbook of Refrigerating Engineering.* Notale among these advances are the phenomenal increase in the food ezing industry, which includes the retail distribution of frozen ems in nearly every food store and the very rapid spread of the eezer locker plant. Summer air conditioning is now used in all pes of commercial buildings, hospitals, railway passenger cars, uses, and in a few homes. The process industries are utilizing the effects of low temperatures in ever increasing measure.

Development of refrigerated warehouses has progressed at a pid rate and a constantly mounting percentage of foodstuffs is ing transported and stored under varying degrees of refrigeration. ransportation employs more and more refrigerated motor trucks d trailers, many of which are cooled by mechanical systems. owever, the railways depend almost exclusively upon ice-cooled frigerator cars for temperatures above freezing, while mixtures salt and ice are used for chilling to subfreezing temperatures. many cases air is circulated over the ice bunkers and the load y means of fans operated from the car wheels.

Within the past few years, the chlorine- and fluorine-substituted ydrocarbon primary refrigerants have proved serious competitors the time tried ammonia, carbon dioxide, and sulphur dioxide. e centrifugal compressor has shown operating advantages for e large scale refrigerating installation, while the absorption sys- em, which had lost popularity to the electrically driven piston ompressor, is now regaining prestige for many applications. Automatic controls have supplanted manual control of both large and mall systems. Welded pipe joints and soldered tubing connectors ve practically eliminated the hazard of leaks in cold storage oms and allow the direct expansion of primary refrigerants in- ead of brine circulation cooling. The attainment of very low mperatures on a large scale, by means of multi-stage compression the cascade system is now an accomplished fact.

The development of refrigeration from a little used luxury to an everyday necessity has covered a relatively short period. I touches, directly or indirectly, the lives of all civilized people Interruption of the service may range from an annoying incident in some cases to the magnitude of disaster in crowded municipalities. Research and invention will constantly broaden the scope of refrigeration and extend the field of its usefulness. While much has been accomplished, this accomplishment has barely ope the door to the scientist and to the engineer; only a good begin has been made. For this reason, engineering students are ur to consider the advisability of including courses in refrigerati in the program of advanced study.

W. R. W
L. H. B.

July, 1948

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The authors wish to express their appreciation of the assistance n in the preparation of this edition of the handbook. Many bles, graphs, and cuts have been reproduced from published aterial and the courtesy of many individuals and organizations s acknowledged. In particular it is desired to thank the American Institute of Chemical Engineers, The American Society of Reigerating Engineers, Baker Ice Machine Company, Inc., Calcium hloride Association, Carbide and Carbon Chemicals Corporation, Carrier Corporation, Crane Company, Curtis Manufacturing Comany, Dow Chemical Company, E. I. du Pont de Nemours and ompany, Frick Company, Frigidaire Division of General Motors orporation, H. J. Heinz Company, Kinetic Chemicals, Inc., inde Air Products Company, Socony-Vacuum Oil Company, ube-Turns, Inc., Vilter Manufacturing Company, York Corporation, and Texas Employers Insurance Association for permission to reproduce copyrighted material. Other tables and data have been incorporated in the text through the courtesy of R. L. Allen, C. R. Queer, R. L. Sweigert, Paul Weber, E. F. White, and Dr. Robert York, Jr. In some instances, tabulated information which has been used by the authors for many years and which has been found to be invaluable to the refrigerating engineer, could not be traced to the original sources. For the use of such material, the authors desire to give general acknowledgment of appreciation.

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SECTION I

FUNDAMENTAL UNITS, DEFINITIONS, CONVERSION FACTORS AND ABBREVIATIONS

FUNDAMENTAL UNITS AND LAWS

Accurate measurement with the ability to convey the measured value to others is one of the basic foundations of engineering. In order to do this it is necessary to have units for each quantity which is to be measured and these units must be familiar to all.

Certain measurements are fundamental, such as those of length, time, mass and temperature. Other units are derived from these fundamental units.

The engineering unit of length is the foot and it is familiar to all in the United States and the United Kingdom. This is also true of the units of time, of mass and of temperature, namely, the second, the pound and the degree Fahrenheit. In a great many cases, the derived units are apparently not connected directly to the fundamental units; however, a careful analysis will show the relation between them.

Heat and Temperature. To the refrigeration engineer, heat energy is of the greatest importance but it is often confused with temperature. Temperature is the intensity factor of heat energy, it is directly perceptible to the human senses, and it determines the tendency of heat to escape from a body which contains this form of energy. The transfer of heat from a body at one temperature occurs only to another body at a lower temperature, but the direction of flow is independent of the quantity of heat energy in either body.

The Fahrenheit degree is $1/180$ of the difference in temperature between ice melting and water boiling at a total pressure of *one* atmosphere. This scale, which is arbitrarily marked 32° at the ice point and 212° at the boiling point, is satisfactory for the measurements of most ordinary temperatures, but it is not sufficient for thermodynamic calculations. Instead the absolute Fahrenheit or Rankine temperature scale is used, which is numerically the temperature in degrees Fahrenheit plus 459.6°. The zero of this scale represents the temperature at which a perfect gas held at a constant volume would exert no pressure upon the walls of the container, and it is defined as the point at which no heat energy is present in the volume of gas. This temperature is 459.6° below the Fahrenheit zero and 491.6° below the freezing point of water.

Heat is often termed the lowest form of energy since all other forms, such as mechanical, chemical, and electrical energy, may be quantitatively converted to heat energy, but the complete conversion of heat into the other forms is not possible. It is the form of energy observed in many applications and characterized by the heterogeneous motion of the molecules of a substance. This motion is completely without order as to direction. It is thus distinguished from the orderly motion which characterizes the usual conception of kinetic energy. Thus, when a body is moving, all of its molecules are in motion in a single direction and the resultant kinetic energy may be directly and completely converted into work. However, if the moving body is stopped by friction and its kinetic energy thus is converted to heat, the orderly motion of translation is used to increase the random movement of the molecules, and this form of energy can be only partially converted to work.

The increase in random molecular energy may manifest itself by an increase in temperature of the body or by a phase change at constant temperature, whereas a decrease of heat energy will reverse the manifestation. A change in temperature is called a change in the "sensible heat" because it is perceptible to human senses. This change is the basis of all measurement of heat energy, since the unit is defined as the quantity of heat required to cause unit weight of pure water to undergo unit temperature change between specified temperature levels. The engineering unit is the British thermal unit, abbreviated Btu, which is approximately the heat required to raise the temperature of one pound of liquid water by one degree Fahrenheit, although the exact definition of the mean Btu is $1/180$ of the heat required to raise the temperature from 32° F. to 212° F. The mechanical equivalent of the mean Btu is 778.26 ft.-lbs.

Specific Heat. When equal weights of two different substances absorb equal quantities of heat energy, the rise in temperature of one is very seldom the same as that of the other. This is due to the molecular structure of the substance, so that varying amounts of heat are required to raise the temperature one degree. The ratio between the heat required to change the temperature of a substance one degree Fahrenheit or Centigrade and that required to change the temperature of an equal weight of water by one degree is known as the *specific heat.* The engineering unit of specific heat is Btu per pound and is the number of British thermal units required to change the temperature of one pound of the substance through an interval of one degree Fahrenheit.

Latent Heat. Under certain conditions, the addition of heat energy produces no change in temperature, but instead the substance undergoes a phase change; that is, the energy is used to cause the internal changes in structure which are necessary to change a solid into a liquid or a liquid into a vapor. Thus, at normal atmospheric pressure the addition of heat energy to ice causes the temperature to rise until 32° F. is reached. At this point the ice melts if more heat is added, but no change in temperature is noted until 143.4 Btu has been added to each pound of ice. Although this quantity of heat has apparently disappeared, so far as the human senses are concerned, it may be completely recovered and is thus merely a latent, or hidden, heat; hence, the quantity 143.4 Btu per lb. is known as the *latent heat of fusion of ice.* It is also equally true that the removal of 143.4 Btu from a pound of liquid water at 32° F. will convert it into ice without any change in temperature.

The continued addition of heat energy to water at 32° F. and one atmosphere pressure will cause the temperature to rise until the boiling point, 212° F., is reached. At this point, further addition of heat will cause no further rise in temperature but instead the liquid will vaporize at constant temperature and it has been found that for every pound of water vaporized 970.3 Btu must be added. This quantity of heat energy is called the *latent heat of vaporization of water.* When the water is completely vaporized, further addition of heat to the vapor will once more cause the temperature to rise. This characteristic behavior is common to all substances that can be melted or vaporized. A certain amount of energy is necessary to change a substance from the solid to the liquid state and another definite quantity is required to change it from the liquid to the vapor or gaseous state.

Energy and Power. Very often these two quantities are confused and the units are sometimes wrongly used. Energy is the capacity to do work and, thus, it may be considered as stored work. Power is the rate at which work is done and it is, therefore, the total work or energy divided by the time required for the performance. The basic engineering unit of energy is the foot-pound, which is the amount of work required to lift a weight of one pound through a vertical distance of one foot. This unit is too small for convenient use and, instead, the horsepower-hour is used, which is the amount of work done by one horsepower acting for one hour, or 1,980,000 ft.-lbs. It is to be noted that while the term "hour" appears in the name of this unit, it is a unit of energy only and is not concerned with time. The unit of power is the horsepower, which is defined as 33,000 ft.-lbs. of work accomplished in one minute. For convenience, the values 550 ft.-lbs. per sec. or 1,980,000 ft.-lbs. per hr. are frequently used.

Other fundamental energy and power units are, respectively, the kilowatt-hour, abbreviated kwh, and the kilowatt, abbreviated kw.

DEFINITIONS

(All units defined are in the f.p.s., or English, system.)

Absolute—Refers to a system of measurements based on the smallest number of arbitrary units.

Absolute Pressure—Pressure above that of an absolute or perfect vacuum. Numerically, it is gage pressure plus the barometric pressure expressed in pounds per square inch.

Absolute Temperature—Temperature above the thermodynamic zero, which is the temperature at which all heat energy is absent. Numerically, it is Fahrenheit temperature plus 459.6°.

Absorber—Apparatus in which gas or vapor is dissolved in a liquid; the low side of an absorption refrigerating system.

Absorption—The process of solution of a gas or vapor in a liquid.

Absorption Refrigerating System—The system in which compression of the refrigerant is secured by thermal means. This is usually accomplished by alternately heating and cooling the absorbing medium. Refrigerant vapor is absorbed at low pressure by the cooled medium and is subsequently discharged at high pressure when the medium is heated.

Adiabatic Process—Any change which occurs in a system without the addition or loss of energy in the form of heat. It is not to be assumed that an adiabatic process is reversible or isentropic.

Adsorption—The attraction to and holding of a gas or vapor upon the surface of a solid. This is characterized by the fact that considerable energy is released when a gas is adsorbed and that this energy must be returned in order to remove the adsorbed substance.

Air Conditioning—Simultaneous control of temperature, humidity, composition, motion and distribution of air for the purpose of human comfort or for industrial utilization.

Analyzer—The unit in an absorption refrigerating machine which removes absorbing liquid from the vapor produced in the generator.

Atmospheric Condenser—A condenser which is cooled by the continuous evaporation of water from the condensing surfaces.

Brine—A water solution of salts, having a freezing point lower than that of pure water. Also any liquid which is used in the refrigeration system for the transfer of heat.

Brine Cooler—An evaporator for cooling brine by means of the evaporation of a primary refrigerant.

British Thermal Unit—The heat energy necessary to raise the temperature of one pound of liquid water one degree Fahrenheit is a unit which is sufficiently accurate for usual engineering computations. The exact unit, the mean Btu, is $1/180$ of the heat required to raise one pound of water from 32° F. to 212° F. at *one* atmosphere pressure.

Capacity, Thermal—The amount of heat energy required to raise the temperature of a mass of material one degree.

Change of State—The process of changing from one state of aggregation to another, such as the change from the solid state to the liquid state or from the liquid state to the gas or vapor state.

Coefficient of Performance—The measure of efficiency of a refrigeration system. Numerically, the amount of heat removed from the refrigerator divided by the work expended.

Compression Refrigerating System—A system in which the refrigerant gas or vapor is compressed by a mechanical device.

Condenser—A vessel or arrangement of tubes in which warm vapor is cooled and liquefied by the removal of heat.

Condensing Unit—The high side of a refrigerating system, which consists of a compressor, condenser, liquid receiver, driving motor or engine and the necessary controls, mounted on one base as a unit.

Conductance, Thermal—Quantity of heat transferred through a body of unit length and unit cross-sectional area in unit time when the temperature gradient along the length dimension is one unit.

Usually expressed in Btu feet per square foot per hour per degree Fahrenheit.

Conduction—The process of heat transmission from molecule to molecule through a body of material.

Convection—The process of transferring heat by the movement of a heated gas, vapor or liquid.

Cooling Tower—Equipment by means of which water or other liquid is brought into intimate contact with air, so that cooling of the liquid by direct evaporation into the air may occur.

Counterflow—Heat exchange between two fluids which flow in opposite directions so that the warmest portion of one fluid meets the warmest portion of the other.

Critical Point—A state point which is characterized by the fact that both liquid and vapor have identical properties.

Critical Pressure—The pressure observed at the critical point of a substance.

Critical Temperature—The temperature observed at the critical point of a substance.

Cycle—A closed path in a thermodynamic system by which the working fluid is brought back after a series of changes to the original conditions of temperature, pressure and enthalpy.

Dalton's Law—The total pressure of a mixture of gases in a closed vessel is the sum of the pressures that each separate gas would exert if the others were not present.

Degree of Superheat—The difference between the temperature of a vapor at a given pressure and the temperature corresponding to saturation at this pressure.

Density—Weight or mass per unit volume; usually expressed in pounds per cubic foot or in pounds per gallon.

Direct Expansion—Process of refrigeration in which material is refrigerated by direct contact with a pipe or vessel in which a refrigerant is being evaporated.

Enclosed Compressor—A machine in which the crank case is pressure tight. Two types of these are known: one in which the crank shaft emerges from the crank case through a packing gland and is driven by an external prime mover; the other is the "hermetically sealed" type in which the driving motor is enclosed in the crank case and is in contact with refrigerant vapor.

Energy—The capacity to do work. The engineering unit of heat energy is the British thermal unit; of mechanical energy, the horsepower-hour; of electrical energy, the kilowatt-hour.

Enthalpy (*Also known as Heat Content and Total Heat*)—The sum of the internal energy plus the product of pressure and volume. Its particular utility is that the energy (heat or other forms) gained or lost by a working fluid in passing through a piece of apparatus is the change of enthalpy of the fluid. The engineering unit of enthalpy is Btu per pound and the mathematical symbol is H.

Entropy—The extensive dimension of heat energy when absolute temperature is employed as the intensive dimension. It is a measure of the unavailable energy of a substance and is a function of the heat energy and the temperature of the substance, which, when multiplied by a lower temperature, shows the energy which cannot be converted to work between the two temperatures. The mathematical symbol for entropy is S.

Eutectic Brine—A solution composed of one or more substances dissolved in water in such proportions that the lowest possible freezing point is secured. *Eutectic Salt Brine* contains 23.3% of dry sodium chloride and freezes at −6.03° F. *Eutectic Calcium Chloride Brine* contains 29.6% of anhydrous calcium chloride and freezes at −59.8° F.

Evaporator—The portion of a refrigerating system in which liquid refrigerant is changed to vapor and absorbs heat from the refrigerator.

Fahrenheit—A thermometer widely used in engineering, in which the scale is graduated to indicate 32° at the freezing point of water under a pressure of one atmosphere and 212° at the boiling point of water under the same pressure.

First Law of Thermodynamics—States that different forms of energy are mutually interconvertible and that a definite numerical ratio exists for each conversion. For instance, if 778.26 ft.-lbs. of mechanical energy are transformed to heat, the quantity of heat energy obtained is always exactly one British thermal unit; one kilowatt-hour of electrical energy is converted to 3412 Btu.

Flooded Evaporator—An evaporator in which the heat-transfer surfaces are always wetted by evaporating liquid refrigerant.

F.p.s. System (*Also Called English System*)—The system of measurement in which the length unit is the foot, the force unit is the pound and the time unit is the second.

Freezer—In cold-storage practice, a refrigerating room which is kept below the freezing temperature of water.

Gas Law or Perfect Gas Law—A mathematical equation which connects the pressure, the volume and absolute temperature of a perfect gas. It is stated as follows: $pv = WRT$, in which p is the pressure exerted by the gas, v is the volume, W is the weight of gas, R is a numerical constant, and T is the absolute temperature. The numerical value of R in the f.p.s. system is 1544 divided by the molecular weight of the gas.

Generator—The boiler or still of an absorption refrigeration system. The device which is used to expel the dissolved refrigerant from the absorbing liquid.

Heat—A basic form of energy which is characterized by its ability to pass from a body at one temperature only to a body at a lower temperature. It may appear as sensible heat or as latent heat. The engineering unit is the British thermal unit, abbreviated Btu.

Heat of Condensation or Liquefaction—Heat energy given up by a vapor or gas during the process of changing to a liquid at constant temperature and pressure.

Heat Exchanger—A device in which heat is transferred from a fluid at one temperature to another fluid at a lower temperature.

Heat, Latent—The heat energy liberated or absorbed in a change of state at constant temperature and pressure. It is not perceptible to human senses and is thus latent, or hidden.

Heat, Sensible—Heat energy which is characterized by change of temperature and is thus perceptible to human senses.

High Side—The portion of a refrigerating system which is under the condenser pressure.

Horsepower—A unit of power, which is work done at the rate of 33,000 ft.-lbs. per min. This is also equivalent to 550 ft.-lbs. per sec. and 1,980,000 ft.-lbs. per hr.

Humidity, Relative—The ratio between the partial pressure of water vapor in air at a given temperature and the saturation pressure of water vapor at the same temperature. This ratio is not dependent upon the atmospheric pressure.

Humidity, Specific—The weight of water vapor in admixture with a unit weight of air. Usually expressed in grains of moisture per pound of dry air.

Hydrometer—Instrument for measuring the specific gravity or the density of a liquid.

Ice-making Capacity—Capacity of a refrigerating system to manufacture ice. This is less than the tonnage refrigerating capacity of the system since it includes energy necessary to cool the water to the freezing point, to remove the latent heat, cool the ice below the freezing point, and to compensate for heat leakage.

Ice-melting Capacity—Refrigeration equal to the latent heat of fusion of a given weight of ice. Numerically, in Btu it is equal to the number of pounds of ice multiplied by 144.

Internal Energy—Energy possessed by a body or system of bodies by virtue of the motions and potential energy of the molecules.

Isentropic Process or Change—One which occurs at constant entropy and hence is completely reversible. All isentropic processes are adiabatic but adiabatic processes are not necessarily isentropic.

Joule's Constant—*See* Mechanical Equivalent of Heat.

Joule-Thompson Effect—Change in temperature of an actual gas or vapor caused by a unit change in pressure which accompanies an irreversible adiabatic throttling process.

Kilowatt—A unit of electric power, abbreviated kw.

Kilowatt-hour—A unit of electrical energy, abbreviated kwh.

Latent Heat—*See* Heat, Latent.

Low Side—The portion of a refrigerating system under the evaporator pressure.

Mechanical Equivalent of Heat—The heat energy evolved by the expenditure of 778.26 ft.-lbs. of mechanical work equals one Btu.

Melting Point—The temperature at which a solid substance changes to the liquid state at a given pressure.

Partial Pressure—The fraction of the total pressure of gas mixture which is exerted by one particular component.

Phase—In a physical sense it is applied to one of the states of matter, such as the solid, liquid or gaseous phase.

Pipe-line Refrigeration—Refrigerating service supplied to a group of buildings from a centrally located refrigerating plant by means of a pipe line.

Polytropic Change of State—Any change in a gas or vapor system represented by the equation pv^n = a constant, in which p is the absolute pressure, v is the volume and n is a numerical constant.

Power—The time rate of doing work. Engineering units: horsepower, kilowatt.

Pressure—The force exerted by a fluid upon a unit area of the wall of a container. Engineering units: pounds per square inch, pounds per square foot, and inches of mercury.

Primary Refrigerant—The fluid which is used in a thermodynamic cycle to remove heat from a low-temperature region and convey it to a high-temperature region.

Quality—Per cent by weight of vapor in a mixture of liquid and vapor.

Quick Freezing—Freezing at a rate sufficiently fast that there is no appreciable change in the physical or chemical properties of the product during the entire cycle of freezing and subsequent thawing.

Raw Water—Any water used for making ice, except distilled water.

Rectifier—A unit of an absorption refrigerating system, in which the concentration of vapor leaving the absorber is increased by cooling and partial condensation of the entrained absorbing liquid.

Refrigerating System—A heat pump. A system by which external work is applied to remove heat from a region of low temperature and discharge it into a region at a higher temperature.

Reversible Cycle or Process—A sequence of events, each of which occurs in such a manner that all original conditions are completely restored by retracing the path of the sequence. Thermodynamically, it is a series of changes by which a definite portion of the thermal energy of a hot substance is allowed to flow to a cool substance in such a manner that the maximum amount of work is done or, if the series of changes occurs in the opposite direction, this amount of work will return the definite portion of thermal energy from the cool substance to the hot substance.

Rotary Compressor—A machine in which compression of a fluid is secured by a rotating member. This is in contradistinction to compressors which use reciprocating members to accomplish the purpose.

Safety Head—The cylinder head of a reciprocating compressor which is held in place by springs, so that an incompressible substance coming between the head and the piston will not cause breakage.

Saturated Vapor—A vapor which is in equilibrium with its liquid phase at the specified temperature and pressure.

Saturation Temperature—The temperature at which the liquid phase and vapor phase of a substance will exist together at a specified pressure.

Second Law of Thermodynamics—The law which states that heat energy may be converted into work only when permitted to pass from a region at one temperature to a region at a lower temperature; and, conversely, heat may be moved from a region at low temperature to one at high temperature only when work is done.

Sensible Heat—See Heat, Sensible.

Sharp Freezer—In refrigerating practice, a room which is used to receive and freeze materials and which is maintained at a temperature below 0° F.

Single-acting Cylinder—A cylinder in which one compression stroke per piston cycle is secured.

Specific Gravity—The ratio of the weight of a given volume of material to the weight of an equal volume of pure water.

Specific Heat—The heat energy required to cause unit change in temperature of unit mass of material.

Specific Volume—The volume occupied by unit weight of material under specified conditions of temperature, pressure and enthalpy.

Standard Cycle Conditions—These are used in the rating of refrigeration machines and consist of the temperatures specified below:

Liquid at the expansion valve, 77° F.
Evaporation temperature, 5° F.
Suction gas to the compressor, 14° F.
Condensing temperature of the vapor at the high pressure, 86° F.

Sub-cooling—The process of cooling a liquid below its condensing or saturation temperature.

Sublimation—The change of state of a solid directly to vapor without passing through the liquid state.

Superheated Vapor—A vapor whose temperature is higher than saturation temperature for the specified pressure.

Thermodynamic Properties—The relationship between the temperature, pressure, specific volume, enthalpy and entropy of a fluid under various conditions.

Ton of Refrigeration—The removal of heat at the rate of 200 Btu per min.

Total Heat—See Enthalpy.

Valve, Expansion—Valve which controls the flow of high-pressure refrigerant to the evaporator.

Vapor—This term is applied to a gas which is near its saturation temperature and pressure. In general, it is usually employed for gases below the critical temperature.

Conversion Factors

Conversion of	*To*	*Use Multiplier*
Acres	Square feet	43,560
Acres	Square rods	160
Acres	Square meters	4,046.9
Acre feet	Cubic feet	43,560
Acre feet	Gallons	325,851
Angstroms	Millimeters	0.0000001
Atmospheres	Inches of mercury	29.92
Atmospheres	Pounds per square inch	14.696
Bags (cement)	Barrels (cement)	0.25
Barrels (dry U. S.)	Barrels (British)	0.706
Barrels (liquid U. S.)	Barrels (British)	0.729
Barrels (liquid U. S.)	Gallons (liquid U. S.)	31.5
Barrels (cement)	Bags (cement)	4
Barrels (oil)	Gallons (U. S.)	42
Boiler horsepower	Btu per hour	33,475
Boiler horsepower	Pounds of water evaporated per hour from and at 212° F.	34.5
Bolts of cloth	Yards	40
British commercial tons refrigeration	Btu per hour	13,253
British thermal unit	Foot-pounds	778.26
Bushels (British)	Bushels (U. S.)	1.032
Bushels (U. S.)	Bushels (British)	0.969
Bushels (U. S.)	Gallons (U. S. dry)	8
Centigrams	Grains	0.154
Centimeters	Inches	0.3937
Centimeters per second	Feet per second	0.0328
Chains (Gunter)	Feet	66
Chains (Ramden)	Feet	100
Circles	Radians	6.2832
Cord	Cubic feet	128
Cubic feet	Gallons (U. S. dry)	6.43
Cubic feet	Gallons (U. S. liquid)	7.48
Cubic feet of water	Pounds water at 39.2° F.	62.42
Cubic feet per second	Gallons per day	646,315
Cubic inches	Cubic centimeters	16.39
Cubic yard of sand	Pounds	2700
Cubits	Inches	18
Days	Minutes	1440
Degrees	Minutes	60
Drams (troy)	Grains	60
Fathoms	Feet	6
Feet	Hands	3
Feet	Inches	12
Feet	Meters	0.305
Feet	Palms	4
Feet elevation of water	Pounds per square foot	62.42
Feet of water	Pounds per square inch	0.434
Feet per second	Miles per hour	0.682
Foot-candles	Lumens per square foot	1
Furlong	Feet	660
Furlong	Miles (U. S.)	0.125

CONVERSION FACTORS (*Continued*)

Conversion of	*To*	*Use Multiplier*
Gallons (British)	Gallons (U. S. liquid)	1.201
Gallons (U. S. dry)	Bushels (U. S.)	0.125
Gallons (U. S. dry)	Gallons (U. S. liquid)	1.164
Gallons (U. S. dry)	Liters	4.048
Gallons (U. S. liquid)	Cubic inches	231
Gallons (U. S. liquid)	Liters	3.785
Gallons per minute	Gallons per day	1440
Gallons of water	Pounds of water at 60° F.	8.34
Grains	Grams	0.0648
Grains per U. S. gallon	Parts per million	17.118
Grams	Grains	15.43
Hands	Inches	4
Hectares	Acres	2.471
Hogshead	Gallons	63
Horsepower	Btu per hour	2545
Horsepower	Btu per minute	42.42
Horsepower	Foot-pounds per minute	33,000
Horsepower	Foot-pounds per second	550
Horsepower	Kilowatts	0.746
Horsepower (Boiler)	Pounds water evaporated per hour from and at 212° F.	34.5
Horsepower (metric)	Horsepower	0.986
Horsepower-year	Horsepower-hours	8760
Inches	Centimeters	2.54
Inches	Mils	1000
Inches of mercury	Pounds per square inch	0.491
Inches of water	Pounds per square inch	0.036
Kilograms	Pounds (avoirdupois)	2.205
Kilometers	Miles (U. S.)	0.621
Kilowatt-hours	Btu	3414
Kilowatts	Horsepower	1.341
Labors (Texas and Spanish areas)	Acres	177.1
Links (Gunters)	Inches	7.92
Liters	Cubic inches (U. S.)	61.02
Liters	Gallons (U. S. dry)	0.227
Liters	Liquid (U. S.)	0.264
Liters per minute	Gallons per minute	0.264
Lumens	Spherical candlepower	0.08
Lumens per square foot	Foot-candles	1
Meters	Feet	3.28
Meters	Inches	39.37
Microns	Angstrom units	10,000
Microns	Millimeters	0.001
Miles (British Admiralty)	Feet	6080
Miles (British nautical)	Feet	6083
Miles (U. S. nautical)	Feet	6080
Miles (U. S. statute)	Feet	5280
Miles per hour	Feet per minute	88
Mils	Inches	0.001
Ounces (avoirdupois)	Grains	437.5
Paces	Inches	30

CONVERSION FACTORS (*Continued*)

Conversion of	*To*	*Use Multiplier*
Palms	Inches	3
Parts per million	Grains per gallon	0.0584
Pennyweights	Grains	24
Perches (masonry)	Cubic feet	24.75
Points (printers)	Inches	0.0139
Poles	Feet	16.5
Pounds (troy)	Kilograms	0.373
Pounds (avoirdupois)	Kilograms	0.454
Pounds (avoirdupois)	Grains	7000
Pounds per square inch	Atmospheres	0.0683
Pounds per square inch	Inches of air	22,640
Pounds per square inch	Inches of mercury	2.04
Pounds per square inch	Inches of water	27.7
Pounds per square inch	Pounds per square foot	144
Proof (U. S.)	Per cent alcoholic volume	0.5
Quarts British	Cubic inches	69.35
Quarts (U. S. dry)	Cubic inches	67.2
Quarts (U. S. liquid)	Cubic inches	57.75
Quires	Sheets	25
Radians	Degrees	57.3
Rods	Feet	16.5
Second-feet	Cubic feet per hour	3,600
Second-feet	Gallons per min.	448.8
Section	Acres	640
Span	Inches	9
Square centimeter	Square inches	0.155
Square inches	Square centimeters	6.45
Square mile	Acres	640
Square mile	Hectares	259
Square millimeters	Circular mils	1974
Tons (long)	Pounds	2240
Tons (metric)	Pounds (avoirdupois)	2205
Tons (shipping space)	Cubic feet	40
Tons (short)	Pounds	2000
Tons of refrigeration (British scientific)	Btu per day	342,860
Tons of refrigeration (British commercial)	Btu per hour	13,253
Tons of refrigeration (U. S.)	Btu per day	288,000
Tons of refrigeration (U. S.)	Btu per hour	12,000
Tons of refrigeration (U. S.)	Btu per minute	200
Varas (Texas and Spanish area)	Feet	2.778
Watts	Btu per hour	3.412
Watt-hour	Btu	3.412
Yards	Meters	0.914

Abbreviations and Symbols for Scientific and Engineering Terms

	Abbreviation	*Symbol*
Absolute	abs.	
Absolute temperature		T
Absolute viscosity		η
Acceleration, gravity		g
Air horsepower	air hp.	
Alternating-current (as adjective)	a-c	
Ampere	amp.	
Area		A
Atmosphere	atm.	
Average	avg.	
Barometer	bar.	
Barrel	bbl.	
Baumé	Bé	
Brake horsepower	bhp.	
Brake horsepower-hour	bhp.-hr.	
British thermal unit	Btu or B	
Bushel	bu.	
Change in specific volume by vaporization		v_{fg}
Conditions at critical point		Subscript c
Circular mils	cir. mils	
Cubic	cu.	
Cubic foot	cu. ft.	
Cubic feet per minute	cfm	
Cubic feet per second	cfs	
Cubic inch	cu. in.	
Cubic yard	cu. yd.	
Cylinder	cyl.	
Degree	deg.	°
Degree Centigrade	C.	
Degree Fahrenheit	F.	
Density		ρ
Diameter	diam.	d, D
Direct-current (as adjective)	d-c	
Dollar		$
Dozen	doz.	
Dry saturated vapor		Subscript g
Efficiency	eff.	e
Electromotive force	emf	E
Enthalpy or heat content		H or h
Entropy		S or s
Exponent of polytropic expansion		n
Feet per minute	fpm	
Feet per second	fps	
Foot	ft.	
Foot-pound	ft.-lb.	
Force		F
Freezing point	fp	
Gallon	gal.	
Gallons per minute	gpm	
Gallons per second	gps	
Gas constant		R
Heat content of dry vapor		h_g or H

ABBREVIATIONS AND SYMBOLS FOR SCIENTIFIC AND ENGINEERING TERMS
(Continued)

	Abbreviation	*Symbol*
Heat content of liquid		h_f or h
Heat equivalent of work		A
Heat of vaporization		h_{fg} or L
Heat transferred per pound		q
Horsepower	hp.	
Horsepower-hour	hp.-hr.	
Hour	hr.	
Inch	in.	
Indicated horsepower	ihp.	
Indicated horsepower-hour	ihp.-hr.	
Inside diameter	ID	
Internal energy		u
Joule's constant		J
Kilovolt	kv	
Kilovolt-ampere	kva	
Kilowatt	kw	
Kinematic viscosity		γ
Length		L
Linear foot	lin. ft.	
Logarithm (common)	log	
Logarithm (natural)	$\log_e$ or ln	
Mass		m
Maximum	max.	
Mean effective pressure	mep	pm
Mechanical efficiency		em
Melting Point	mp	
Meter	m.	
Miles per hour	mph	
Minimum	min.	
Minute	min.	
Minute (angular measure)		$'$
Molecular weight	mol. wt.	M
Ounce	oz.	
Overall coefficient of heat transfer		U
Parts per million	ppm	
Pound	lb.	
Pounds per cubic foot	lb. per cu. ft.	
Pounds per square foot	psf.	
Pounds per square inch	psi.	
Pounds per square inch absolute	psia.	
Power		P
Power factor	pf.	
Pressure		p
Quality of steam or vapor		x
Quantity-total		Q
Quart	qt.	
Radius	rad.	r
Ratio of specific heats		k
Revolutions per unit time		ω
Second	sec.	
Specific gravity	sp. gr.	
Specific heat	sp. ht.	c

ABBREVIATIONS AND SYMBOLS FOR SCIENTIFIC AND ENGINEERING TERMS
(*Continued*)

	Abbreviation	*Symbol*
Specific heat, constant pressure		c_p
Specific heat, constant volume		c_v
Specific volume		v
Square	sq.	
Square foot	sq. ft.	
Square inch	sq. in.	
Surface coefficient of heat transfer		f
Temperature	temp.	T
Temperature, absolute		T
Thermal conductivity		k
Thermal conductance		C
Thermal resistance		R
Thermal transmission		q
Time		t
Volt-ampere	va	
Wall thickness		x
Watt	w	
Watt hour	whr	
Weight	wt.	
Weight, total		W
Weight rate		W
Weight, mass velocity		G
Work per unit weight		w
Yard	yd.	
Year	yr.	

TABLE 1–1

SCHEMATIC WIRING SYMBOLS

(BY PERMISSION OF FRIGIDAIRE DIV., GEN. MOTORS CORP.)

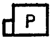
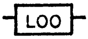
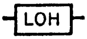
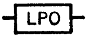
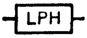
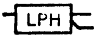
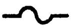
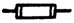
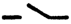
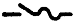
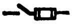
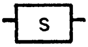
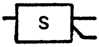
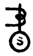
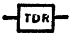
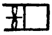
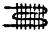
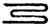
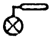
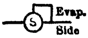
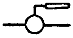
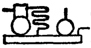
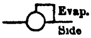
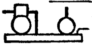
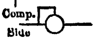
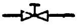
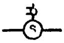
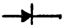
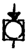
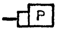
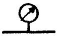
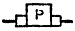
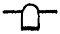
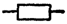
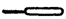
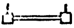
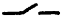
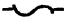
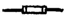
Thermostat		A temperature actuated control switch
Pressurestat		A pressure actuated control switch
Controller		Any automatic (temperature, pressure or time actuated) switch as may be applied
Low Pressure Switch		Low Pressure control only, "L" may be replaced with "T" indicating a thermostatic instead of low pressure element.
		Low Pressure control with High Pressure cutout
		Low Pressure control with Over Current protection
		Low Pressure control with Over Current protection and High Pressure cutout
		Power take-off ahead of over current heater element
Fuse or Fusetron		Fuse in one side of circuit (usually a Fusetron unless located in a switch)
		All lines fused for line protection
Manual Switch		Disconnecting or controlling switch
		Switch with fuse in one line
		Switch with all lines fused
Starter		Magnetic motor starting device either across-the-line or reduced voltage type, with manually reset over current protection
		Power take-off ahead of over current heater elements
Solenoid Valve		Magnetic stop valve for electrically controlled "On or Off" operation in liquid or suction line
Motor		Either AC or DC, usually designated for application as "Comp." "Fan," "Pump," etc.
Time Delay Relay		Slow acting relay usually with an adjustable time delay of from 2 to 30 seconds by a dash-dot arrangement

Table 1–2

STANDARD REFRIGERATION SYMBOLS

(By Permission of Frigidaire Div., Gen Motors Corp.)

	Forced Convection Unit		Hand Expansion Valve
	Finned Type Cooling Unit Natural Convection		Automatic Expansion Valve (AXV)
	Pipe Coil		Thermostatic Expansion Valve (TXV)
	Immersion Cooling Unit		Evaporator Pressure Regulating Valve Snap Action Valve (SAV)
	Ice Making Unit		Evaporator Pressure Regulating Valve Thermostatic Throttling Type (TRV)
	Condensing Unit Air Cooled		Evaporator Pressure Regulating Valve Throttling Type (ERV or LTV)
	Condensing Unit Water Cooled		Compressor Suction Pressure Limiting Valve Throttling Type (CRV)
	Compressor		Hand Shut-off Valve
	Evaporative Condenser		Solenoid Valve
	Cooling Tower		Check Valve
	AC Motor		Low Side Float
	DC Motor		High Side Float
	Pressurestat		Gauge
	Pressurestat With High Pressure Cut-out		Scale Trap
	Thermostat Self-contained		Strainer
	Thermostat With Remote Bulb		Drier
	Thermal Bulb		Heat Exchanger
	Square Feet		Disconnect Switch
	Square Inches	 	One Side } Fuse Complete } Fuse
	Cubic Feet	ϕ	Phase Referring to Alternating Current
#	Pounds	∿	Cycle Referring to Alternating Current

SECTION II

PRIMARY REFRIGERANTS

Primary Refrigerant. A primary refrigerant is the medium which is used in a thermodynamic cycle to remove heat from a low-~~temperature~~ region and convey it to a high-temperature region. ~~Of the~~ materials that are commercially employed at the present time, the "vapors" are the only ones of importance. Although there is no known ideal primary refrigerant, many of the vapors possess numerous desirable qualities and a minimum number of undesirable characteristics. These may be divided empirically into thermodynamic properties, chemical behavior, safety factors and economic characteristics.

Thermodynamic Properties. Manifestly, any refrigerant which is to be circulated through a system must have a freezing temperature below the minimum operating range and it is desirable that the critical point lie above the maximum condenser temperature. The condensing pressure at ordinary atmospheric temperature should be sufficiently low to avoid the expense of equipment and piping of unusual strength. It is desirable that the evaporating pressure at refrigerator temperature should not be less than one atmosphere in order to avoid leakage of air into the system. A high latent heat value is also advantageous since this will assure the circulation of the minimum weight of refrigerant and a minimum loss of energy through the irreversible process occurring in the expansion valve.

The specific heat of the liquid should be low to minimize the transfer of sensible heat to the refrigerator. High specific heat of the vapor and good thermal conductivity of both vapor and liquid increase the rate of heat transfer. Low viscosity of both liquid and vapor decreases frictional resistance to flow and allows the use of small pipe sizes.

Chemical Behavior. Stability of the refrigerant is important in order to avoid decomposition under the conditions of temperature and pressure prevailing in the different parts of the cycle. There should be little tendency either in the presence or absence of moisture to corrode the standard metals of construction which will be used in the apparatus. It is desirable that the fluid should not interfere with proper lubrication if it is to be used in piston or rotary compressors. Since there are no rubbing parts exposed to the refrigerant in centrifugal compressors, this characteristic is unnecessary in such machines. To prevent stoppage of expansion valves by ice, the refrigerant should dissolve water and hold it in solution at low temperatures.

Safety Factors. Refrigerants which are inflammable or explosive are manifestly undesirable. They should be nontoxic to human beings and livestock in any concentration which is likely to be encountered and should also be noninjurious to foodstuffs or other materials with which they might accidentally come into contact. The refrigerant used in air-conditioning systems should be almost completely nontoxic since, in case of serious leaks or failure in the piping, the entire contents of the system might be suddenly discharged into the building. Strong odor to which people are unaccustomed is also undesirable since it might occasion a panic-disaster in crowded auditoriums should a leak occur. However, it is desirable that the refrigerant should possess enough of an odor so that it can be readily detected in case of serious leaks.

Economic Characteristics. The cost of the refrigerant is often important, although in a well-maintained system the losses are usually very slight. However, the ready commercial availability and the maintenance of ample stocks at distributing points is of great importance. The detection of leakage should not be slow and cumbersome since in such a case many leaks would be permitted to exist, thus entailing a considerable wastage of primary refrigerant. The conventional seals used on rotating shafts and reciprocating piston rods should retain the refrigerant efficiently.

AMMONIA

This primary refrigerant has long been the standard for operation of large plants. Its thermodynamic properties are excellent, the critical temperature is sufficiently high and the freezing point sufficiently low to lie outside the operating range of the majority of applications. The latent heat exceeds that of any other refrigerant except water. Condensing pressure at ordinary atmospheric temperature usually does not exceed 165 lbs. gage and the evaporating pressure is above that of the atmosphere until −28° F. is reached. The chemical stability is satisfactory, although a slow decomposition into gaseous hydrogen and nitrogen does occur at the high temperature of the gas leaving the compressor. Ammonia is completely noncorrosive to iron or steel construction and does not affect the packing and gasket materials which are commonly used. However, in the presence of water and atmospheric oxygen, pure copper and copper-containing alloys are rapidly attacked, and it is therefore necessary to avoid such construction materials in the ammonia system.

Mineral oils are almost insoluble in this refrigerant and dilution of the lubricant is thus avoided. The viscosity index is of the greatest importance since the oil must lubricate at the very high temperature of the compressor and yet maintain fluidity in the evaporator. Oils of animal or vegetable origin cannot be employed as cylinder lubricants, as they are rapidly converted into soaps by ammonia. No serious difficulty is encountered in retaining this refrigerant by means of conventional seals or packing materials.

From the standpoint of hazard, this refrigerant is far from ideal since it is poisonous when inhaled in moderate concentration and its strong odor is conducive to panic in case of leaks. However, the odor is so penetrating that ample warning is fairly certain before dangerous concentrations are attained. It is not easily inflammable but will burn under certain conditions and may form violently explosive mixtures with air. Ammonia is almost never used in air-conditioning systems because of these dangers, but its other advantages recommend it for many industrial refrigerating plants.

Ammonia is one of the cheapest of all refrigerants with the exception of water and, since it has many industrial uses besides that of refrigeration, it is readily available in almost any civilized community. The detection of leaks is very easy, as ammonia is perceptible to the sense of smell in concentrations as low as 5 parts per 100,000 of air. The exact location of the leak may be quite easily shown by the dense white fumes produced by a burning sulphur taper or by the use of test papers or solutions which change color in the presence of ammonia. Phenol-phthalein paper or solution assumes a reddish color and Nessler's reagent becomes yellow to brown in the presence of this refrigerant. Table 2–1 lists the important properties of ammonia.

TABLE 2-1. PROPERTIES OF AMMONIA

Chemical symbol	NH_3
Freezing point, °F	−108
Boiling point at atmospheric pressure, °F	−28
Conditions at critical point:	
Temperature, °F	271
Pressure, lbs. per sq. in. abs.	1650
Specific heat of vapor at constant pressure at 68° F.	0.524
Specific heat of vapor at constant volume at 68° F.	0.400
Latent heat of vaporization at one atmosphere, Btu per pound	589.3
Suction pressure at 5° F., lbs. per sq. in. abs.	34.27
Condensing pressure at 86° F., lbs. per sq. in. abs.	169.2
Toxicity, Underwriters Laboratories Grouping	2
Explosive limits (by volume in air)	16–25%

THE "FREON" REFRIGERANTS

Since the commercial production of the chloro- and fluoro-substituted methanes and ethanes has been accomplished, these refrigerants have assumed great importance. A large number of these compounds are known and it is probable that many have properties which make them desirable for specialized refrigerating applications, but at the present time only six are employed as primary refrigerants. These are marketed under the trade name "Freon," together with a code number which identifies the particular compound.

Dichlorodifluoromethane, also known as "Freon 12," is widely used in all types of refrigerating machines. For use in reciprocating compressors, operating in conjunction with evaporators at abnormally low temperatures, monochlorodifluoromethane (Freon 22) is particularly suitable because of its relatively high vapor pressure. Dichloromonofluoromethane (Freon 21), trichloromonofluoromethane (Freon 11), dichlorotetrafluoroethane (Freon 114) and trichlorotrifluoroethane (Freon 113) are largely used in centrifugal compressors.

The thermodynamic properties of this family of refrigerants cover a very wide range, but all have critical temperatures considerably higher than are likely to prevail in the condenser and, with the exception of Freon 113 which freezes at −31° F., all have freezing points below −106° F. Coefficients of performance very closely approximate that of ammonia.

Chemical stability is a common property of the group and none of them attacks, any of the metals which are commonly found in the refrigerating system. Lubricating oils are completely miscible in the liquids at ordinary temperature but may separate into two phases at very low temperatures.

Perhaps the most marked characteristic of these refrigerants is the small hazard to life and property in case of leakage. The concentration of vapor in air to produce toxic effects in experimental animals during respiration tests is above 10% by volume and would be difficult to attain even in case of complete failure of commercial machines. Generally, the vapors are reported to be completely without odor in moderate concentration, but some individuals are able to detect leaks by the sense of smell. However, there is no marked odor or irritant property which might incite panic when large amounts of vapor are present in the air.

Foodstuffs are not damaged, nor is there any change in flavor or appearance on contact with these refrigerants. The vapors are either noninflammable or are combustible only with great difficulty; however, contact with burning materials causes the formation of acrid poisonous gases.

The fact that these refrigerants are almost without odor renders the quick detection of leaks difficult, and serious losses may not be noticed by the operator. The most convenient form of leak detector is the Halide lamp, which is essentially a pressure-type torch having a copper burner tip and using alcohol for fuel. The presence of volatile halogen compounds in the air will cause the flame of this lamp to assume a greenish to azure tint. A flexible tube is attached to the burner to permit air from the neighborhood of a suspected leak to enter the combustion zone. By this method it is possible to locate the position of a leak with a fair degree of accuracy, but the final test is to paint the suspected area with soap solution and note the formation of bubbles.

Water cannot be permitted to accumulate in a system using halogenated hydrocarbons, as the ice formed will choke the expansion valve. In addition it reacts slowly with the refrigerant, forming acids which are corrosive to metals.

This group of refrigerants is somewhat more expensive than ammonia and, because the density is greater, a much larger weight is necessary to charge a given system. However, in any well-maintained plant the loss of refrigerant during operation is negligible and thus the unit price is not a primary consideration. Table 2-2 lists the properties of this group of refrigerants.

TABLE 2-2. PROPERTIES OF CHLOROFLUOROMETHANES AND ETHANES *

	Monochlorodifluoromethane (Freon 22)	Dichlorodifluoromethane (Freon 12)	Dichlorotetrafluoroethane (Freon 114)	Dichloromonofluoromethane (Freon 21)	Trichloromonofluoromethane (Freon 11)	Trichlorotrifluoroethane (Freon 113)
Chemical formula	$CHClF_2$	CCl_2F_2	$C_2Cl_2F_4$	$CHCl_2F$	CCl_3F	$C_2Cl_3F_3$
Freezing point, °F.	−256	−252	−137	−211	−168	−31
Boiling point at one atmosphere, °F.	−41.4	−21.6	38.4	48.0	74.7	117.6
Conditions at critical point:						
Temperature, °F.	204.8	232.7	294.3	353.3	388.4	417.4
Pressure, lbs. per sq in abs	716	582	474	750	635	495
Specific heat of vapor at constant pressure at one atmosphere, °F.	0.1499 at 68	0.1446 at 68	0.1629 at 110	0.1364 at 60	0.1374 at 110	0.1633 at 160
Specific heat of vapor at constant volume at one atmosphere, °F.	0.1261 at 68	0.1273 at 68	0.1502 at 110	0.1156 at 60	0.1213 at 110	0.1516 at 160
Latent °F. heat of vaporization at 5° F..	93.45	69.47	61.98	109.34	84.00	70.62
Suction pressure at 5° F, lbs per sq in abs.	43.12	26.51	6.77	5.243	2.931	0.9802
Condensing pressure at 86° F., lbs per sq in. abs	174.2	107.9	36.69	31.23	18.28	7.856
Coefficient of performance, standard rating cycle	4.68	4.72	4.75	4.89	4.87	4.93
Toxicity, Underwriters Laboratories Grouping	5A	6	6	4	5	6 †

* This group of refrigerants is characterized by almost complete freedom from fire and explosion hazard.
† Indicates manufacturers' grouping.

METHYL CHLORIDE

This refrigerant has been widely used in the packaged refrigerating units up to approximately 10 tons capacity. The thermodynamic characteristics are satisfactory, although the rather low vapor pressure necessitates considerably larger units than ammonia for a given capacity. The low operating pressures are, however, an advantage in the smaller units, since correspondingly light wall piping and pressure vessels may be employed. Methyl chloride is less stable chemically than the Freon refrigerants and is classed by the Underwriters Laboratories as moderately inflammable with a moderate explosion hazard. It is a nonirritant and has only a faint ethereal odor. Frequently, a small per cent of acrolein is added as a warning agent in case of leaks. This mixture has a marked odor and is highly irritating to the eyes and nose. Water rapidly reacts with the refrigerant to form a mixture of methyl alcohol and hydrochloric acid, which attacks most construction materials with extreme vigor. For this reason, it is necessary to insure at all times that only traces of water are present in the system. With the exception of this property, methyl chloride is suitable for use with any ordinary metal, except aluminum.

It is reported that a minimum amount of difficulty attends the retention of this substance by ordinary seals which are used on reciprocating rods or rotating shafts. Small leaks in the system may be located by means of the Halide torch, which has been described in the foregoing. However, since mixtures of this refrigerant and air can explode, it is recommended that leaks be located by means of soap solution. Table 2-3 lists the properties of methyl chloride.

TABLE 2-3. PROPERTIES OF METHYL CHLORIDE

Chemical symbol	CH_3Cl
Freezing point	144
Boiling point at atmospheric pressure	−10.76
Conditions at critical point:	
Temperature, °F	289.4
Pressure, lbs. per sq. in. abs.	969.2
Specific heat of vapor at constant pressure at 77° F.	0.199
Specific heat of vapor at constant volume at 77° F.	0.155
Latent heat of vaporization at one atmosphere, Btu per lb.	194.28
Suction pressure at 5° F., lbs. per sq. in. abs.	21.15
Condensing pressure at 86°F., lbs. per sq. in. abs.	94.7
Toxicity	4 *
Inflammability, explosive limits (by volume in air)	8.1–17.2%

* Grouping of Classification of Underwriters Laboratories Report MH-2375.

SULPHUR DIOXIDE

This refrigerant, which was formerly rather widely used in household refrigerators, has now fallen somewhat into disfavor. Its evaporating pressure at refrigerator temperatures and condensing pressure at ordinary atmospheric temperatures are lower than the corresponding values for methyl chloride. This necessitates compressors of great volumetric capacity, which fact has largely prevented its employment in the larger refrigerating systems. It is well adapted for use in apparatus made largely from copper, although water must be rigidly excluded from the system, since in the presence of water this refrigerant forms sulphurous acid, which vigorously attacks metal.

The hazard to human life is rather high, but since the odor of the refrigerant is so penetrating ample warning is given, except in the case of sudden, complete structural failure of the system. Since sulphurous acid attacks all metals vigorously, there is danger of corrosion around plants using this refrigerant, and its presence in food is not desirable.

Sulphur dioxide is noninflammable and nonexplosive. Other properties are listed in Table 2–4.

TABLE 2–4. PROPERTIES OF SULPHUR DIOXIDE

Chemical symbol	SO_2
Freezing point, °F.	−98.9
Boiling point at atmospheric pressure, °F.	13.8
Conditions at critical point:	
Temperature, °F.	314.8
Pressure, lbs. per sq. in. abs.	1141.5
Specific heat of vapor at constant pressure at 68° F.	0.1516
Specific heat of vapor at constant volume at 68° F.	0.1175
Latent heat of vaporization at one atmosphere, Btu per lb.	167.15
Suction pressure at 5° F., lbs. per sq. in. abs.	11.81
Condensing pressure at 86° F., lbs. per sq. in. abs.	66.45
Toxicity, Underwriters Laboratories Grouping	1

CARBON DIOXIDE

This refrigerant is probably the safest of all the primary fluids which have been used, with the exception of air and water. Its thermodynamic properties are not particularly desirable for refrigeration, since the low critical temperature, 87.8° F., requires the condenser temperature to be held below this figure. Condensing pressure is exceedingly high and thus the heaviest construction is necessary for the compressors and condensers. This is not a completely unmitigated evil, since the high pressure results in a very low specific volume and, consequently, compressors may be made quite small for a given capacity. It is completely stable under all conditions of operation and is noncorrosive to all construction materials. Lubricating oils are almost completely insoluble in the liquid and this facilitates the separation and removal of lubricant from condensers and evaporators. This refrigerant is odorless and is not dangerous to life in any concentration below 4%, although in larger concentrations it acts as a suffocant. Leaks in carbon dioxide systems can be detected only by means of the bubbles produced in soap solutions.

In addition to its use as a refrigerant, carbon dioxide is widely employed for charging beverages and has many uses in the chemical industry; thus it is readily available and its cost is low. Table 2-5 lists properties of carbon dioxide.

TABLE 2-5. PROPERTIES OF CARBON DIOXIDE

Chemical symbol	CO_2
Triple point, °F	−69.9
Subliming point at atmospheric pressure, °F	−109.3
Conditions at critical point:	
Temperature, °F	87.8
Pressure, lbs. per sq. in. abs.	1070
Specific heat of vapor at constant pressure at 68° F.	0.1988
Specific heat of vapor at constant volume at 68° F.	0.1525
Latent heat of sublimation at one atmosphere, Btu per lb.	246.3
Suction pressure at 5° F., lbs. per sq. in. abs.	332.0
Condensing pressure at 86° F., lbs. per sq. in. abs.	1043
Toxicity, Underwriters Laboratories Grouping	5
Inflammability	Noncombustible

WATER

Water has excellent thermodynamic properties, with the single exception that its freezing point is 32° F. However, since many refrigeration systems are operated at temperatures above this point, water has been used as a working fluid. The specific volume of the vapor at normal atmospheric temperature is very great and this precludes the use of reciprocating compressors, but the steam jet compressors or aspirators are used with success. Table 2-6 lists the properties of water.

TABLE 2-6. PROPERTIES OF WATER

Chemical symbol	H_2O
Freezing point, °F.	32.0
Boiling point at atmospheric pressure, °F.	212.0
Conditions at critical point:	
Temperature, °F.	705.4
Pressure, lbs. per sq. in. abs.	3206
Specific heat of vapor at constant pressure at 212° F.	0.4836
Specific heat of vapor at constant volume at 212° F.	0.3652
Latent heat of vaporization at one atmosphere, Btu per lb.	970.3
Suction pressure at 32° F., lbs. per sq. in. abs.	0.0887
Condensing pressure at 86° F., lbs. per sq. in. abs.	0.615

ETHYLENE

For low-temperature refrigeration, ethylene has been successfully employed in cascade systems which use a second primary refrigerant to remove heat from the ethylene condenser. As the critical temperature is only 49.8° F., it cannot be used in a multistage compression system when the condenser temperature may exceed this value. The low solidification point, −272.5° F., gives a very wide operating range which covers many of the low-temperature applications. One of the principal advantages of ethylene is that the evaporating pressure is greater than one atmosphere at all temperatures above −154.7° F. and that the condensing pressures are not excessive.

The gas is an anesthetic when high concentrations are present in air, but in general the health hazard is low. It is easily inflammable and forms violently explosive mixtures with air; thus, ethylene machines must be designed and operated with this characteristic constantly in mind. Table 2–7 lists the properties of ethylene.

TABLE 2–7. PROPERTIES OF ETHYLENE

Chemical symbol	C_2H_4
Freezing point, °F.	−272.5
Boiling point at one atmosphere, °F.	−154.7
Conditions at critical point:	
Temperature, °F.	49.8
Pressure, lbs. per sq. in. abs.	742
Specific heat of vapor at constant pressure at 68° F.	0.359
Specific heat of vapor at constant volume at 68° F.	0.286
Latent heat of vaporization at one atmosphere, Btu per lb.	207.9

METHANE, ETHANE, PROPANE, ISOBUTANE AND BUTANE

These hydrocarbons have been proposed and used to a limited extent as refrigerants. The boiling points at atmospheric pressure range from −277.6° F. for methane to 31.5° F. for butane; thus, almost the entire refrigeration range is covered by these five hydrocarbons. However, the inflammability of these gases and their explosive properties in admixture with air have greatly limited the degree of utilization. Isobutane and butane have been used in small units where the total amount of refrigerant present is insignificant and is not likely to add appreciably to the hazard during a fire of sufficient severity to destroy the machine. Propane is often employed as the refrigerant and as a solvent in dewaxing of lubricating oils at low temperature. The oil to be treated is mixed with liquefied propane under high pressure; then upon a reduction of pressure, the evaporation chills the solution directly to a temperature which causes wax to precipitate in a form suitable for mechanical separation. Propane has also been used in refrigerated transport service, functioning both as the primary refrigerant and as fuel for the driving motor.

Other refrigerants that have received application in the field of refrigeration are carbon tetrachloride, chloroform, dichloroethylene, ethyl chloride, ethylamine, methylamine, methylene chloride, methyl formate, and trichloroethylene.

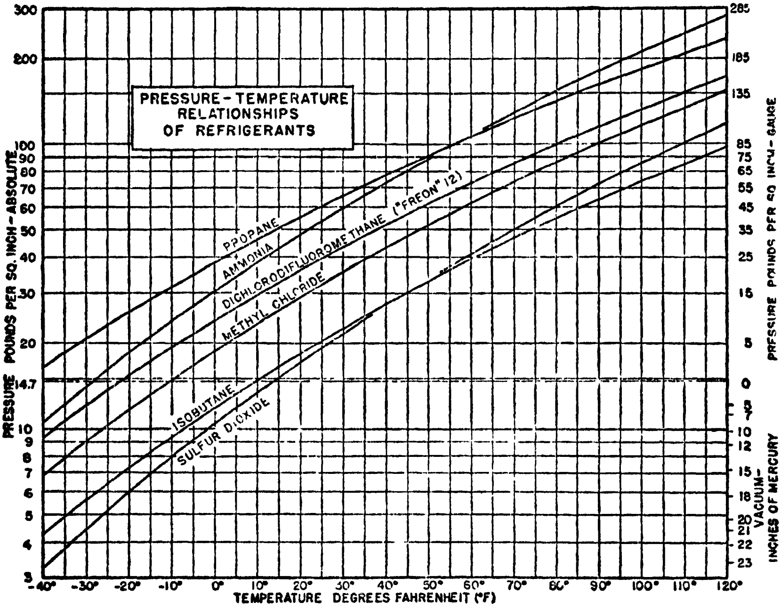


Fig. 2–1.

The abridged tables of the properties of the saturated vapor of these refrigerants are given subsequently together with some of the physical properties. These tables are arranged alphabetically after the more commonly used refrigerants and the hydrocarbon group.

SECTION IIA

PRIMARY REFRIGERANT CHARTS AND TABLES OF THERMODYNAMIC CHARACTERISTICS

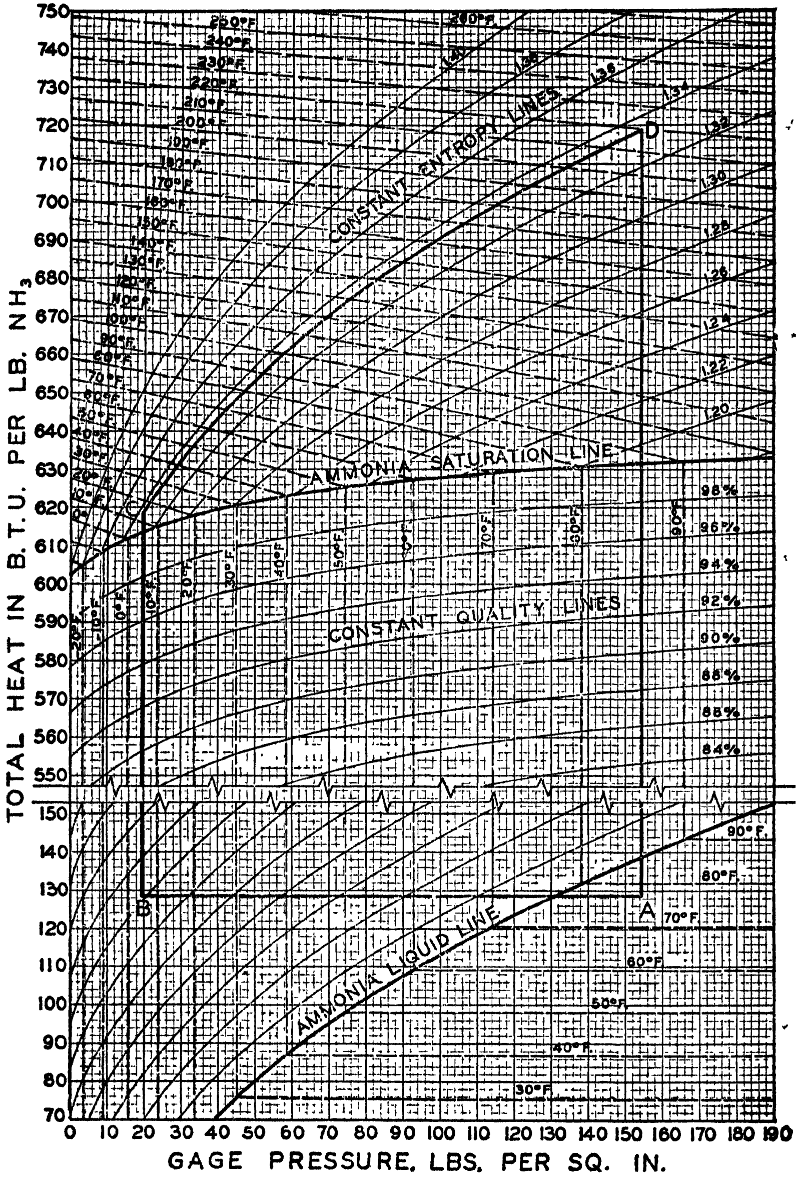


Fig. 2A–1. Pressure-enthalpy chart for ammonia.

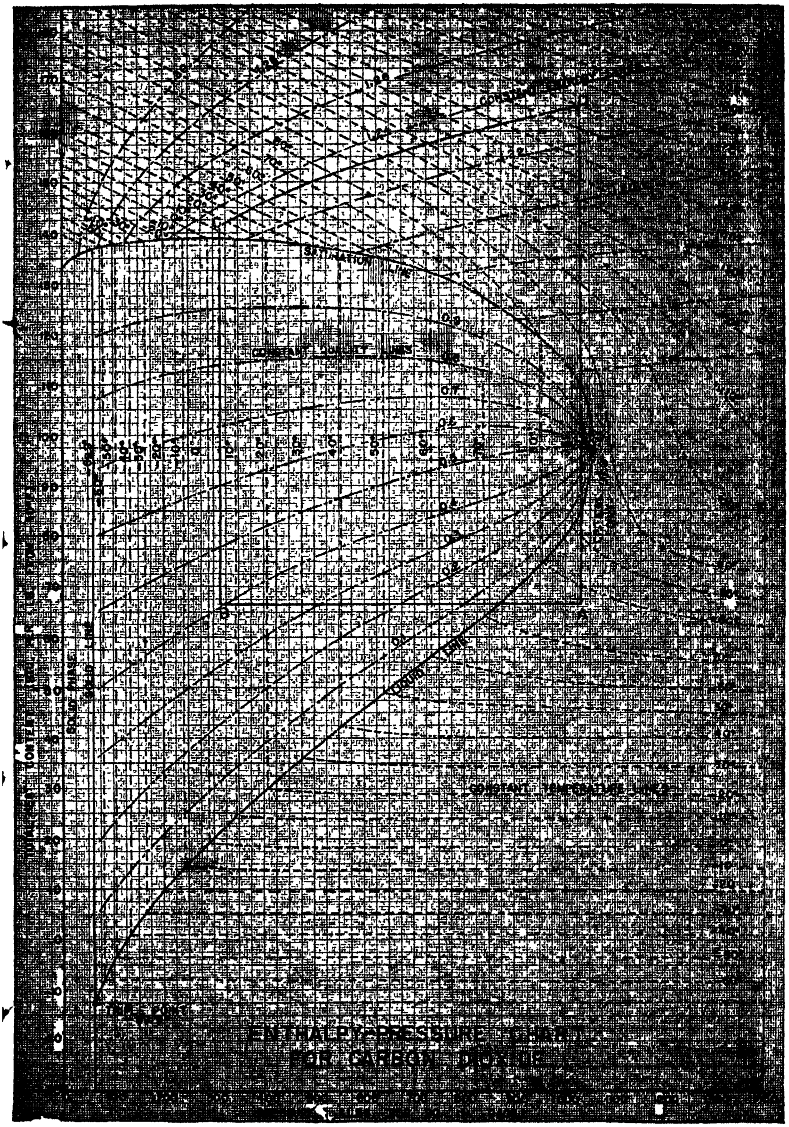


FIG. 2A–2. Pressure-enthalpy chart for carbon dioxide with standard ton cycle and critical point indicated.

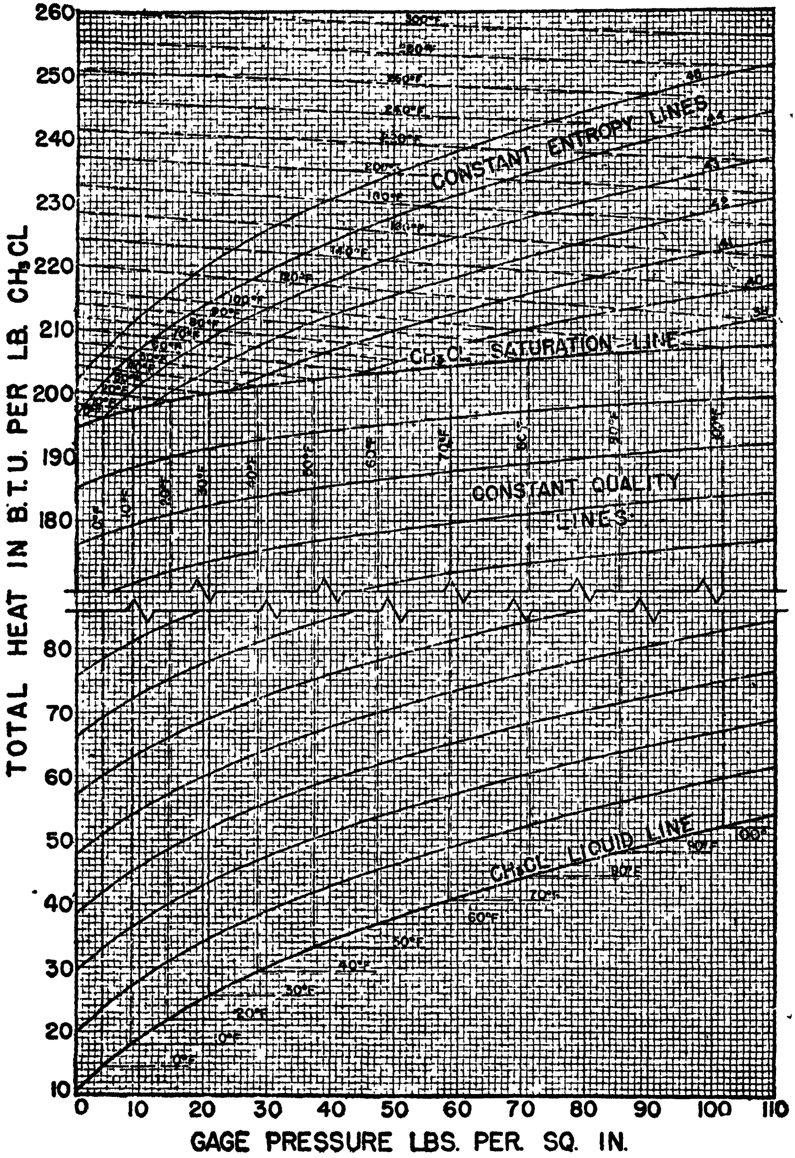


Fig. 2a–3. Pressure-enthalpy chart for methyl chloride.

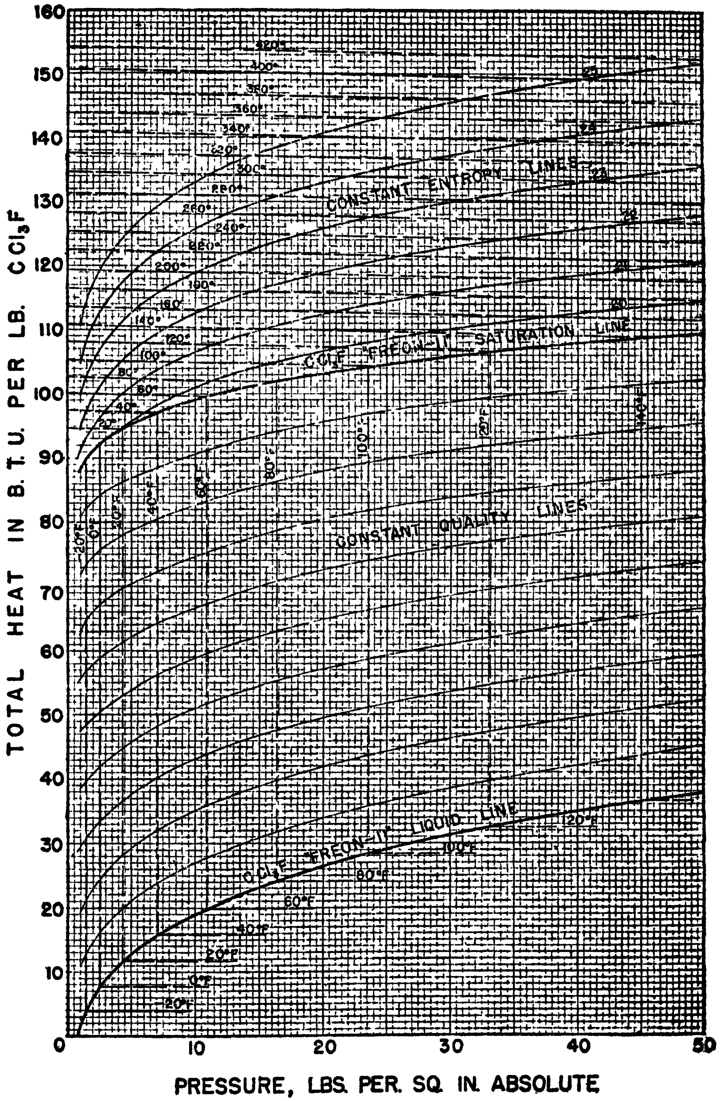


Fig. 2a–5. Pressure-enthalpy chart for Freon 11.

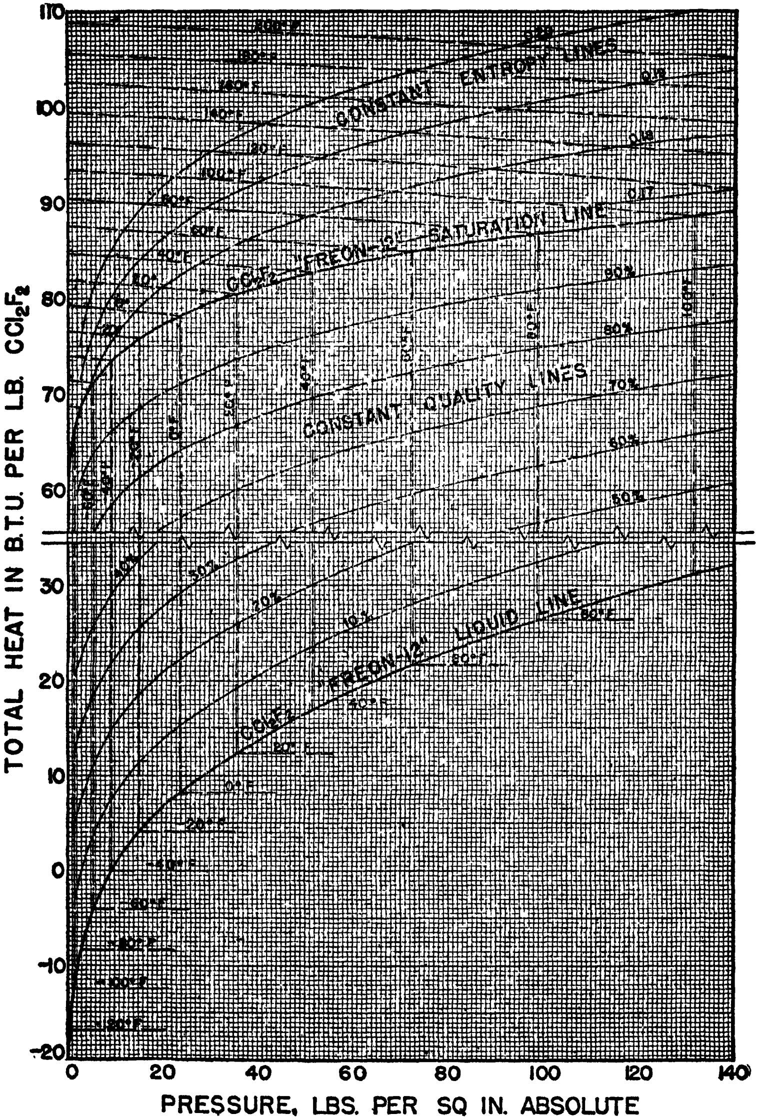


Fig. 2A–6. Pressure-enthalpy chart for Freon 12.

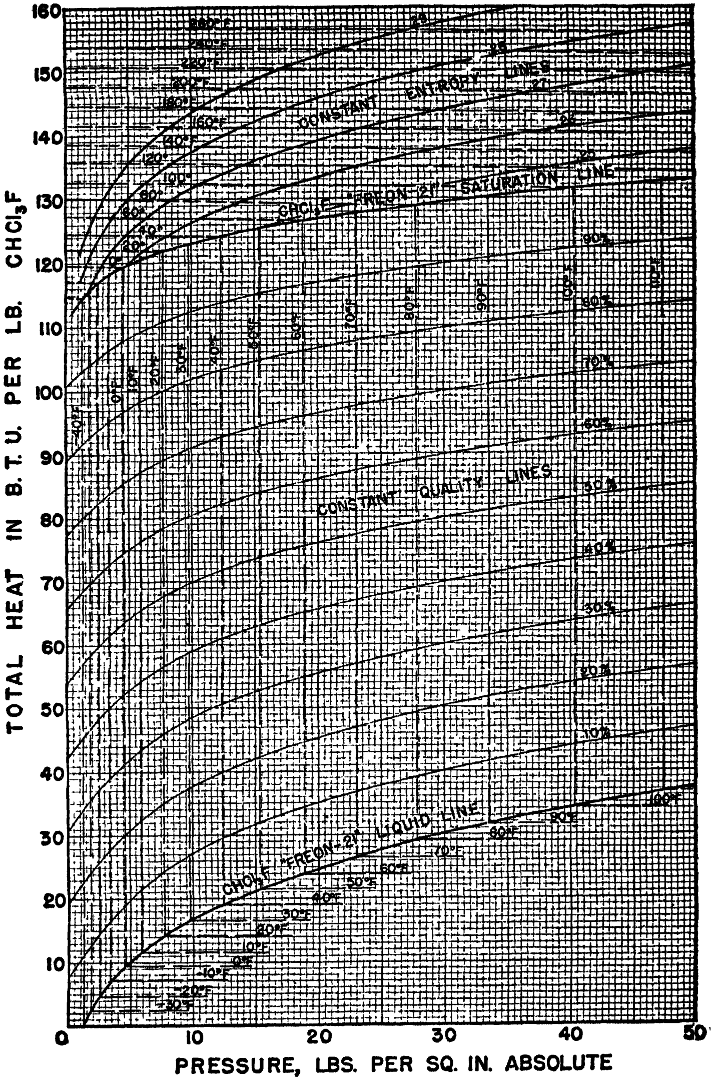


Fig. 2A–7. Pressure-enthalpy chart for Freon 21.

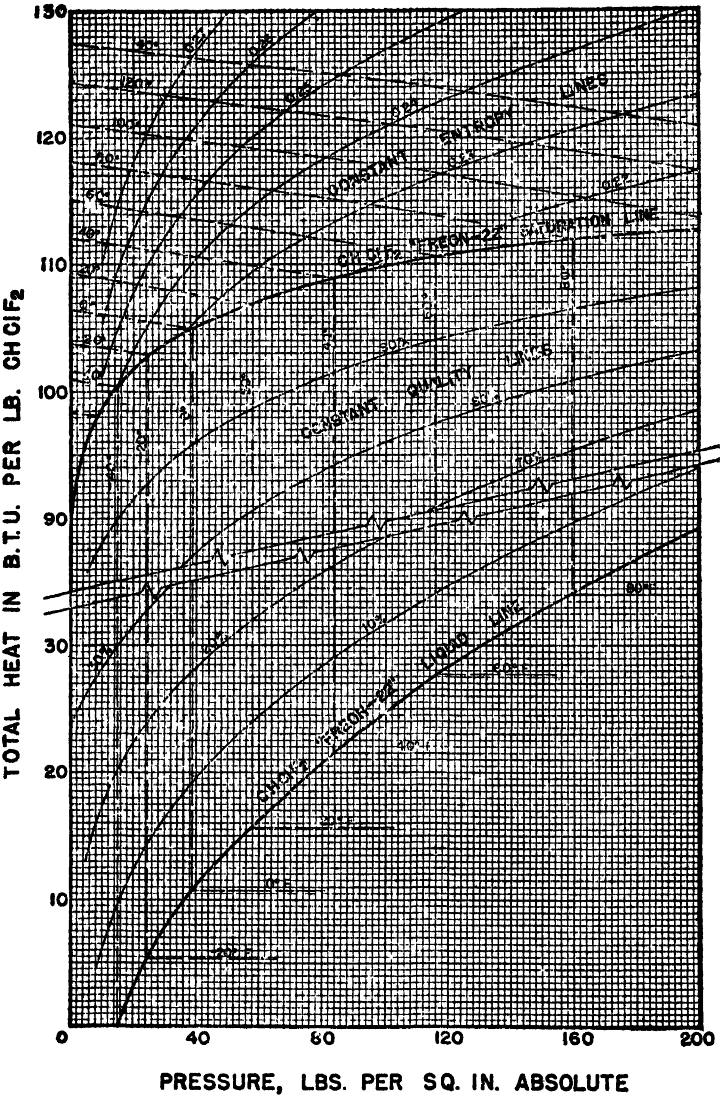


Fig. 2a–8. Pressure-enthalpy chart for Freon 22.

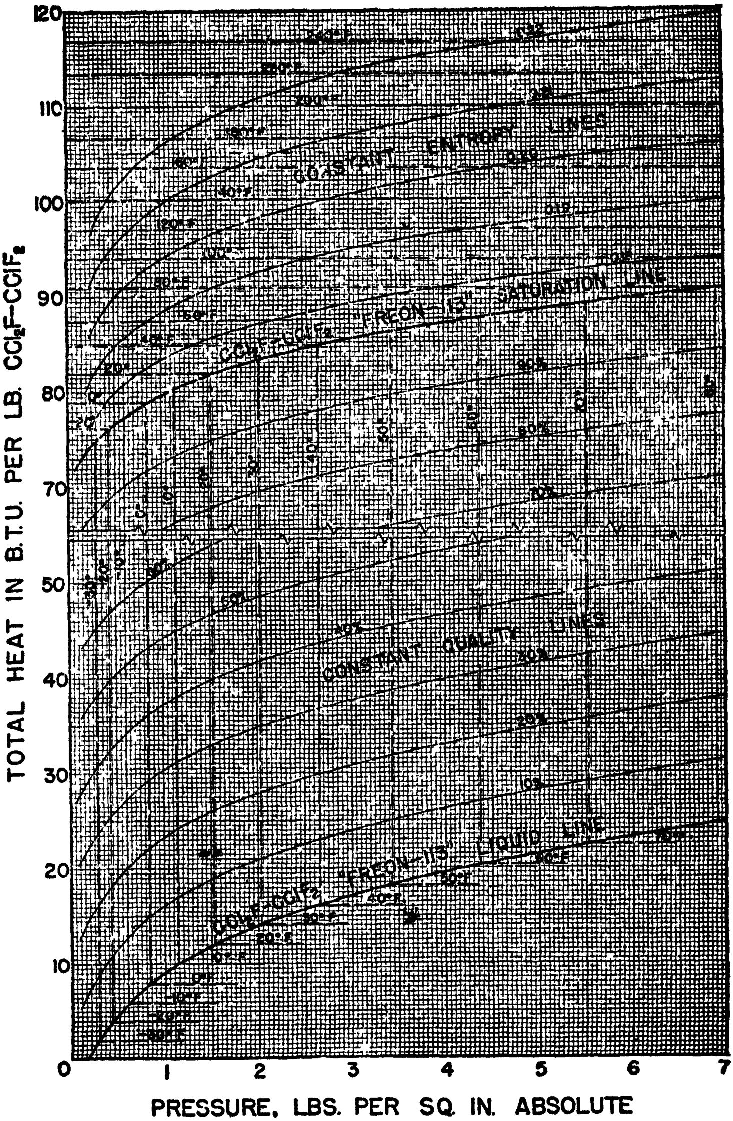


Fig. 2a–9. Pressure-enthalpy chart for Freon 113.

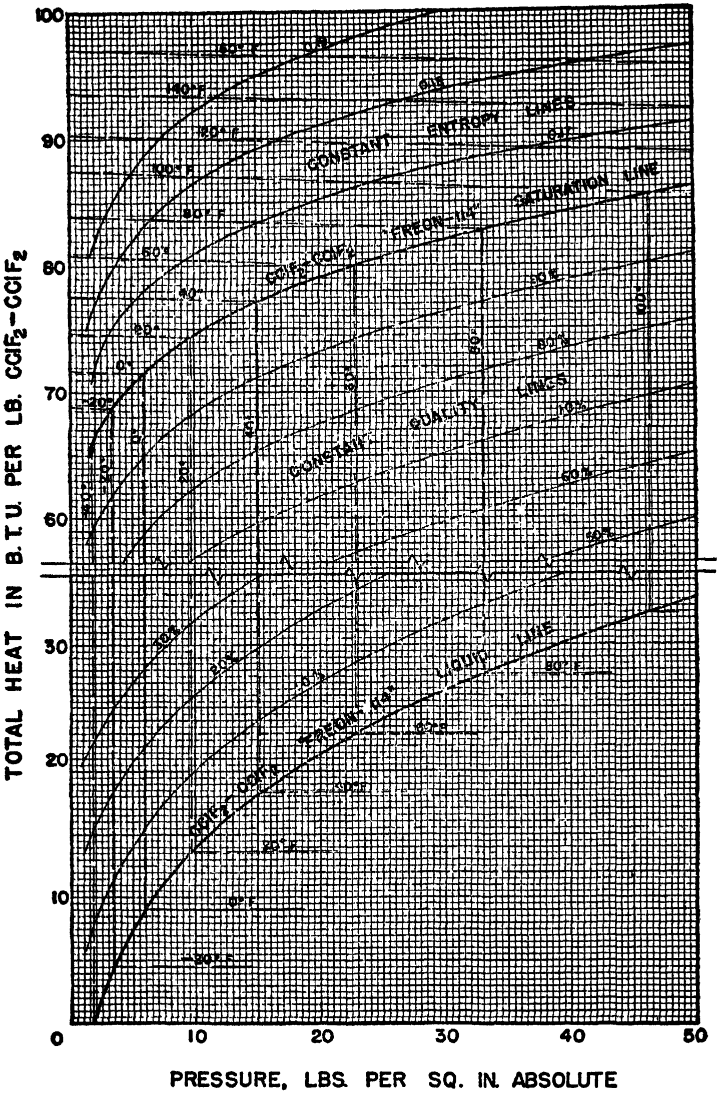


Fig. 2a-10. Pressure-enthalpy chart for Freon 114.

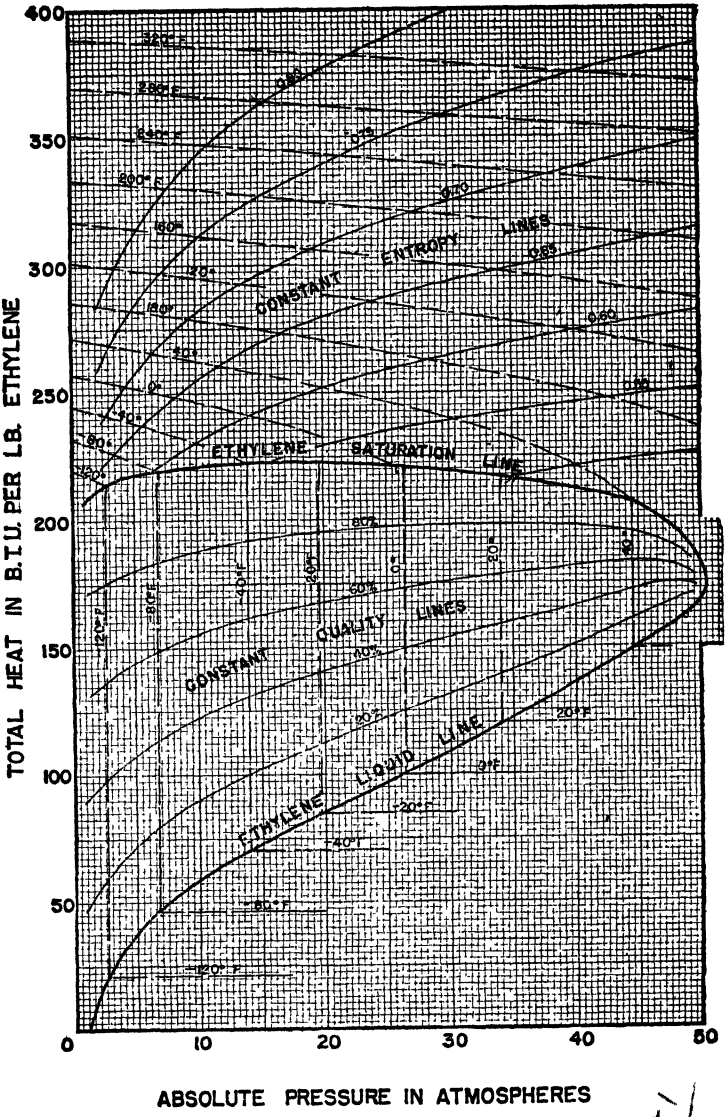


Fig. 2A–11. Pressure-enthalpy chart for ethylene.

Government of India,
DELHI POLYTECHNIC
6651

AMMONIA

TABLE 2A-1. PROPERTIES OF SATURATED AMMONIA

(Computed and arranged by the U. S. Bureau of Standards)

	Pressure.				Enthalpy From − 40°.			Entropy.		
Temp. °F.	Absolute. lbs./in.²	Gage. lbs./in.²	Volume vapor. ft³/lb.	Density vapor. lbs /ft.³	Liquid. Btu./lb.	Vapor. Btu./lb.	Latent heat. Btu./lb.	Liquid. Btu./lb.°F.	Vapor. Btu./lb.°F.	Temp. °F.
t	p	$g.p.$	V	$1/V$	h	H	L	s	S	t
−60	5.55	*18.6	44.73	0.02235	−21.2	589.6	610.8	−0.0517	1.4769	−60
−59	5.74	*18.2	43.37	.02306	−20.1	590.0	610.1	−.0490	.4741	−59
−58	5.93	*17.8	42.05	.02378	−19.1	590.4	609.5	−.0464	.4713	−58
−57	6.13	*17.4	40.79	.02452	−18.0	590.8	608.8	−.0438	.4686	−57
−56	6.33	*17.0	39.56	.02528	−17.0	591.2	608.2	−.0412	.4658	−56
−55	6.54	*16.6	38.38	0.02605	−15.9	591.6	607.5	−0.0386	1.4631	−55
−54	6.75	*16.2	37.24	.02685	−14.8	592.1	606.9	−.0360	.4604	−54
−53	6.97	*15.7	36.15	.02766	−13.8	592.4	606.2	−.0334	.4577	−53
−52	7.20	*15.3	35.09	.02850	−12.7	592.9	605.6	−.0307	.4551	−52
−51	7.43	*14.8	34.06	.02936	−11.7	593.2	604.9	−.0281	.4524	−51
−50	7.67	*14.3	33.08	0.03023	−10.6	593.7	604.3	−0.0256	1.4497	−50
−49	7.91	*13.8	32.12	.03113	−9.6	594.0	603.6	−.0230	.4471	−49
−48	8.16	*13.3	31.20	.03205	−8.5	594.4	602.9	−.0204	.4445	−48
−47	8.42	*12.8	30.31	.03299	−7.4	594.9	602.3	−.0179	.4419	−47
−46	8.68	*12.2	29.45	.03395	−6.4	595.2	601.6	−.0153	.4393	−46
−45	8.95	*11.7	28.62	0.03494	−5.3	595.6	600.9	−0.0127	1.4368	−45
−44	9.23	*11.1	27.82	.03595	−4.3	596.0	600.3	−.0102	.4342	−44
−43	9.51	*10.6	27.04	.03698	−3.2	596.4	599.6	−.0076	.4317	−43
−42	9.81	*10.0	26.29	.03804	−2.1	596.8	598.9	−.0051	.4292	−42
−41	10.10	*9.3	25.56	.03912	−1.1	597.2	598.3	−.0025	.4267	−41
−40	10.41	*8.7	24.86	0.04022	0.0	597.6	597.6	0.0000	1.4242	−40
−39	10.72	*8.1	24.18	.04135	1.1	598.0	596.9	.0025	.4217	−39
−38	11.04	*7.4	23.53	.04251	2.1	598.3	596.2	.0051	.4193	−38
−37	11.37	*6.8	22.89	.04369	3.2	598.7	595.5	.0076	.4169	−37
−36	11.71	*6.1	22.27	.04489	4.3	599.1	594.8	.0101	.4144	−36
−35	12.05	*5.4	21.68	0.04613	5.3	599.5	594.2	0.0126	1.4120	−35
−34	12.41	*4.7	21.10	.04739	6.4	599.9	593.5	.0151	.4096	−34
−33	12.77	*3.9	20.54	.04868	7.4	600.2	592.8	.0176	.4072	−33
−32	13.14	*3.2	20.00	.04999	8.5	600.6	592.1	.0201	.4048	−32
−31	13.52	*2.4	19.48	.05134	9.6	601.0	591.4	.0226	.4025	−31
−30	13.90	*1.6	18.97	0.05271	10.7	601.4	590.7	0.0250	1.4001	−30
−29	14.30	*0.8	18.48	.05411	11.7	601.7	590.0	.0275	.3978	−29
−28	14.71	0.0	18.00	.05555	12.8	602.1	589.3	.0300	.3955	−28
−27	15.12	0.4	17.54	.05701	13.9	602.5	588.6	.0325	.3932	−27
−26	15.55	0.8	17.09	.05850	14.9	602.8	587.9	.0350	.3909	−26
−25	15.98	1.3	16.66	0.06003	16.0	603.2	587.2	0.0374	1.3886	−25
−24	16.42	1.7	16.24	.06158	17.1	603.6	586.5	.0399	.3863	−24
−23	16.88	2.2	15.83	.06317	18.1	603.9	585.8	.0423	.3840	−23
−22	17.34	2.6	15.43	.06479	19.2	604.3	585.1	.0448	.3818	−22
−21	17.81	3.1	15.05	.06644	20.3	604.6	584.3	.0472	.3796	−21
−20	18.30	3.6	14.68	0.06813	21.4	605.0	583.6	0.0497	1.3774	−20
−19	18.79	4.1	14.32	.06985	22.4	605.3	582.9	.0521	.3752	−19
−18	19.30	4.6	13.97	.07161	23.5	605.7	582.2	.0545	.3729	−18
−17	19.81	5.1	13.62	.07340	24.6	606.1	581.5	.0570	.3708	−17
−16	20.34	5.6	13.29	.07522	25.6	606.4	580.8	.0594	.3686	−16
−15	20.88	6.2	12.97	0.07709	26.7	606.7	580.0	0.0618	1.3664	−15
−14	21.43	6.7	12.66	.07898	27.8	607.1	579.3	.0642	.3643	−14
−13	21.99	7.3	12.36	.08092	28.9	607.5	578.6	.0666	.3621	−13
−12	22.56	7.9	12.06	.08289	30.0	607.8	577.8	.0690	.3600	−12
−11	23.15	8.5	11.78	.08490	31.0	608.1	577.1	.0714	.3579	−11
−10	23.74	9.0	11.50	0.08695	32.1	608.5	576.4	0.0738	1.3558	−10

* Inches of mercury below one standard atmosphere (29.92 in.).

TABLE 2A-1. PROPERTIES OF SATURATED AMMONIA (*Continued*)

(*Computed and arranged by the U. S. Bureau of Standards*)

Temp. °F.	Pressure.		Volume vapor. ft³/lb.	Density vapor. lbs./ft.³	Enthalpy From − 40°		Latent heat Btu./lb.	Entropy.		Temp. °F.
	Absolute. lbs./in.²	Gage. lbs./in.²			Liquid. Btu./lb.	Vapor. Btu./lb.		Liquid Btu./lb. °F.	Vapor. Btu./lb. °F.	
t	*p*	*g. p.*	*V*	*1/V*	*h*	*H*	*L*	*s*	*S*	*t*
−10	23.74	9.0	11.50	0.08695	32.1	608.5	576.4	0.0738	1.3558	−10
−9	24.35	9.7	11.23	.08904	33.2	608.8	575.6	.0762	.3537	−9
−8	24.97	10.3	10.97	.09117	34.3	609.2	574.9	.0786	.3516	−8
−7	25.61	10.9	10.71	.09334	35.4	609.5	574.1	.0809	.3495	−7
−6	26.26	11.6	10.47	.09555	36.4	609.8	573.4	.0833	.3474	−6
−5	26.92	12.2	10.23	0.09780	37.5	610.1	572.6	0.0857	1.3454	−5
−4	27.59	12.9	9.991	.1001	38.6	610.5	571.9	.0880	.3433	−4
−3	28.28	13.6	9.763	.1024	39.7	610.8	571.1	.0904	.3413	−3
−2	28.98	14.3	9.541	.1048	40.7	611.1	570.4	.0928	.3393	−2
−1	29.69	15.0	9.326	.1072	41.8	611.4	569.6	.0951	.3372	−1
0	30.42	15.7	9.116	0.1097	42.9	611.8	568.9	0.0975	1.3352	0
1	31.16	16.5	8.912	.1122	44.0	612.1	568.1	.0998	.3332	1
2	31.92	17.2	8.714	.1148	45.1	612.4	567.3	.1022	.3312	2
3	32.69	18.0	8.521	.1174	46.2	612.7	566.5	.1045	.3292	3
4	33.47	18.8	8.333	.1200	47.2	613.0	565.8	.1069	.3273	4
5	34.27	19.6	8.150	0.1227	48.3	613.3	565.0	0.1092	1.3253	5
6	35.09	20.4	7.971	.1254	49.4	613.6	564.2	.1115	.3234	6
7	35.92	21.2	7.798	.1282	50.5	613.9	563.4	.1138	.3214	7
8	36.77	22.1	7.629	.1311	51.6	614.3	562.7	.1162	.3195	8
9	37.63	22.9	7.464	.1340	52.7	614.6	561.9	.1185	.3176	9
10	38.51	23.8	7.304	0.1369	53.8	614.9	561.1	0.1208	1.3157	10
11	39.40	24.7	7.148	.1399	54.9	615.2	560.3	.1231	.3137	11
12	40.31	25.6	6.996	.1429	56.0	615.5	559.5	.1254	.3118	12
13	41.24	26.5	6.847	.1460	57.1	615.8	558.7	.1277	.3099	13
14	42.18	27.5	6.703	.1492	58.2	616.1	557.9	.1300	.3081	14
15	43.14	28.4	6.562	0.1524	59.2	616.3	557.1	0.1323	1.3062	15
16	44.12	29.4	6.425	.1556	60.3	616.6	556.3	.1346	.3043	16
17	45.12	30.4	6.291	.1590	61.4	616.9	555.5	.1369	.3025	17
18	46.13	31.4	6.161	.1623	62.5	617.2	554.7	.1392	.3006	18
19	47.16	32.5	6.034	.1657	63.6	617.5	553.9	.1415	.2988	19
20	48.21	33.5	5.910	0.1692	64.7	617.8	553.1	0.1437	1.2969	20
21	49.28	34.6	5.789	.1728	65.8	618.0	552.2	.1460	.2951	21
22	50.36	35.7	5.671	.1763	66.9	618.3	551.4	.1483	.2933	22
23	51.47	36.8	5.556	.1800	68.0	618.6	550.6	.1505	.2915	23
24	52.59	37.9	5.443	.1837	69.1	618.9	549.8	.1528	.2897	24
25	53.73	39.0	5.334	0.1875	70.2	619.1	548.9	0.1551	1.2879	25
26	54.90	40.2	5.227	.1913	71.3	619.4	548.1	.1573	.2861	26
27	56.08	41.4	5.123	.1952	72.4	619.7	547.3	.1596	.2843	27
28	57.28	42.6	5.021	.1992	73.5	619.9	546.4	.1618	.2825	28
29	58.50	43.8	4.922	.2032	74.6	620.2	545.6	.1641	.2808	29
30	59.74	45.0	4.825	0.2073	75.7	620.5	544.8	0.1663	1.2790	30
31	61.00	46.3	4.730	.2114	76.8	620.7	543.9	.1686	.2773	31
32	62.29	47.6	4.637	.2156	77.9	621.0	543.1	.1708	.2755	32
33	63.59	48.9	4.547	.2199	79.0	621.2	542.2	.1730	.2738	33
34	64.91	50.2	4.459	.2243	80.1	621.5	541.4	.1753	.2721	34
35	66.26	51.6	4.373	0.2287	81.2	621.7	540.5	0.1775	1.2704	35
36	67.63	52.9	4.289	.2332	82.3	622.0	539.7	.1797	.2686	36
37	69.02	54.3	4.207	.2377	83.4	622.2	538.8	.1819	.2669	37
38	70.43	55.7	4.126	.2423	84.6	622.5	537.9	.1841	.2652	38
39	71.87	57.2	4.048	.2470	85.7	622.7	537.0	.1863	.2635	39
40	73.32	58.6	3.971	0.2518	86.8	623.0	536.2	0.1885	1.2618	40

TABLE 2A-1. PROPERTIES OF SATURATED AMMONIA (*Continued*)

(*Computed and arranged by the U. S. Bureau of Standards*)

Temp. °F t	Pressure.		Volume vapor. ft.^{3}/lb. V	Density vapor lbs/ft.^{3} $1/V$	Enthalpy From − 40°.		Latent heat Btu./lb. L	Entropy.		Temp. °F. t
	Absolute. lbs./in.^{2} p	Gage lbs./in.^{2} $g. p.$			Liquid. Btu /lb. h	Vapor. Btu /lb. H		Liquid Btu./lb °F. s	Vapor. Btu./lb.°F. S	
40	73.32	58.6	3.971	0.2518	86.8	623.0	536.2	0.1885	1.2618	40
41	74.80	60.1	3.897	.2566	87.9	623.2	535.3	.1908	.2602	41
42	76.31	61.6	3.823	.2616	89.0	623.4	534.4	.1930	.2585	42
43	77.83	63.1	3.752	.2665	90.1	623.7	533.6	.1952	.2568	43
44	79.38	64.7	3.682	.2716	91.2	623.9	532.7	.1974	.2552	44
45	80.96	66.3	3.614	0.2767	92.3	624.1	531.8	0.1996	1.2535	45
46	82.55	67.9	3.547	.2819	93.5	624.4	530.9	.2018	.2519	46
47	84.18	69.5	3.481	.2872	94.6	624.6	530.0	.2040	.2502	47
48	85.82	71.1	3.418	.2926	95.7	624.8	529.1	.2062	.2486	48
49	87.49	72.8	3.355	.2981	96.8	625.0	528.2	.2083	.2469	49
50	89.19	74.5	3.294	0.3036	97.9	625.2	527.3	0.2105	1.2453	50
51	90.91	76.2	3.234	.3092	99.1	625.5	526.4	.2127	.2437	51
52	92.66	78.0	3.176	.3149	100.2	625.7	525.5	.2149	.2421	52
53	94.43	79.7	3.119	.3207	101.3	625.9	524.6	.2171	.2405	53
54	96.23	81.5	3.063	.3265	102.4	626.1	523.7	.2192	.2389	54
55	98.06	83.4	3.008	0.3325	103.5	626.3	522.8	0.2214	1.2373	55
56	99.91	85.2	2.954	.3385	104.7	626.5	521.8	.2236	.2357	56
57	101.8	87.1	2.902	.3446	105.8	626.7	520.9	.2257	.2341	57
58	103.7	89.0	2.851	.3508	106.9	626.9	520.0	.2279	.2325	58
59	105.6	90.9	2.800	.3571	108.1	627.1	519.0	.2301	.2310	59
60	107.6	92.9	2.751	0.3635	109.2	627.3	518.1	0.2322	1.2294	60
61	109.6	94.9	2.703	.3700	110.3	627.5	517.2	.2344	.2278	61
62	111.6	96.9	2.656	.3765	111.5	627.7	516.2	.2365	.2262	62
63	113.6	98.9	2.610	.3832	112.6	627.9	515.3	.2387	.2247	63
64	115.7	101.0	2.565	.3899	113.7	628.0	514.3	.2408	.2231	64
65	117.8	103.1	2.520	0.3968	114.8	628.2	513.4	0.2430	1.2216	65
66	120.0	105.3	2.477	.4037	116.0	628.4	512.4	.2451	.2201	66
67	122.1	107.4	2.435	.4108	117.1	628.6	511.5	.2473	.2186	67
68	124.3	109.6	2.393	.4179	118.3	628.8	510.5	.2494	.2170	68
69	126.5	111.8	2.352	.4251	119.4	628.9	509.5	.2515	.2155	69
70	128.8	114.1	2.312	0.4325	120.5	629.1	508.6	0.2537	1.2140	70
71	131.1	116.4	2.273	.4399	121.7	629.3	507.6	.2558	.2125	71
72	133.4	118.7	2.235	.4474	122.8	629.4	506.6	.2579	.2110	72
73	135.7	121.0	2.197	.4551	124.0	629.6	505.6	.2601	.2095	73
74	138.1	123.4	2.161	.4628	125.1	629.8	504.7	.2622	.2080	74
75	140.5	125.8	2.125	0.4707	126.2	629.9	503.7	0.2643	1.2065	75
76	143.0	128.3	2.089	.4786	127.4	630.1	502.7	.2664	.2050	76
77	145.4	130.7	2.055	.4867	128.5	630.2	501.7	.2685	.2035	77
78	147.9	133.2	2.021	.4949	129.7	630.4	500.7	.2706	.2020	78
79	150.5	135.8	1.988	.5031	130.8	630.5	499.7	.2728	.2006	79
80	153.0	138.3	1.955	0.5115	132.0	630.7	498.7	0.2749	1.1991	80
81	155.6	140.9	1.923	.5200	133.1	630.8	497.7	.2769	.1976	81
82	158.3	143.6	1.892	.5287	134.3	631.0	496.7	.2791	.1962	82
83	161.0	146.3	1.861	.5374	135.4	631.1	495.7	.2812	.1947	83
84	163.7	149.0	1.831	.5462	136.6	631.3	494.7	.2833	.1933	84
85	166.4	151.7	1.801	0.5552	137.8	631.4	493.6	0.2854	1.1918	85

TABLE 2A-1. PROPERTIES OF SATURATED AMMONIA (*Continued*)

(Computed and arranged by the U. S. Bureau of Standards)

Temp. °F.	Pressure.		Volume vapor. ft.³/lb.	Density vapor. lbs./ft.³	Enthalpy From − 40°.		Latent heat. Btu./lb.	Entropy.		Temp. °F.
	Absolute. lbs./in.²	Gage. lbs./in.²			Liquid. Btu./lb.	Vapor. Btu./lb.		Liquid. Btu./lb.°F.	Vapor. Btu./lb.°F.	
t	*p*	*g.p.*	*V*	*1/V*	*h*	*H*	*L*	*s*	*S*	*t*
85	166.4	151.7	1.801	0.5552	137.8	631.4	493.6	0.2854	1.1918	**85**
86	169.2	154.5	1.772	.5643	138.9	631.5	492.6	.2875	.1904	86
87	172.0	157.3	1.744	.5735	140.1	631.7	491.6	.2896	.1889	87
88	174.8	160.1	1.716	.5828	141.2	631.8	490.6	.2917	.1875	88
89	177.7	163.0	1.688	.5923	142.4	631.9	489.5	.2937	.1860	89
90	180.6	165.9	1.661	0.6019	143.5	632.0	488.5	0.2958	1.1846	**90**
91	183.6	168.9	1.635	.6116	144.7	632.1	487.4	.2979	.1832	91
92	186.6	171.9	1.609	.6214	145.8	632.2	486.4	.3000	.1818	92
93	189.6	174.9	1.584	.6314	147.0	632.3	485.3	.3021	.1804	93
94	192.7	178.0	1.559	.6415	148.2	632.5	484.3	.3041	.1789	94
95	195.8	181.1	1.534	0.6517	149.4	632.6	483.2	0.3062	1.1775	**95**
96	198.9	184.2	1.510	.6620	150.5	632.6	482.1	.3083	.1761	96
97	202.1	187.4	1.487	.6725	151.7	632.8	481.1	.3104	.1747	97
98	205.3	190.6	1.464	.6832	152.9	632.9	480.0	.3125	.1733	98
99	208.6	193.9	1.441	.6939	154.0	632.9	478.9	.3145	.1719	99
100	211.9	197.2	1.419	0.7043	155.2	633.0	477.8	0.3166	1.1705	**100**
101	215.2	200.5	1.397	.7159	156.4	633.1	476.7	.3187	.1691	101
102	218.6	203.9	1.375	.7270	157.6	633.2	475.6	.3207	.1677	102
103	222.0	207.3	1.354	.7384	158.7	633.3	474.6	.3228	.1663	103
104	225.4	210.7	1.334	.7498	159.9	633.4	473.5	.3248	.1649	104
105	228.9	214.2	1.313	0.7615	161.1	633.4	472.3	0.3269	1.1635	**105**
106	232.5	217.8	1.293	.7732	162.3	633.5	471.2	.3289	.1621	106
107	236.0	221.3	1.274	.7852	163.5	633.6	470.1	.3310	.1607	107
108	239.7	225.0	1.254	.7972	164.6	633.6	469.0	.3330	.1593	108
109	243.3	228.6	1.235	.8095	165.8	633.7	467.9	.3351	.1580	109
110	247.0	232.3	1.217	0.8219	167.0	633.7	466.7	0.3372	1.1566	**110**
111	250.8	236.1	1.198	.8344	168.2	633.8	465.6	.3392	.1552	111
112	254.5	239.8	1.180	.8471	169.4	633.8	464.4	.3413	.1538	112
113	258.4	243.7	1.163	.8600	170.6	633.9	463.3	.3433	.1524	113
114	262.2	247.5	1.145	.8730	171.8	633.9	462.1	.3453	.1510	114
115	266.2	251.5	1.128	0.8862	173.0	633.9	460.9	0.3474	1.1497	**115**
116	270.1	255.4	1.112	.8996	174.2	634.0	459.8	.3495	.1483	116
117	274.1	259.4	1.095	.9132	175.4	634.0	458.6	.3515	.1469	117
118	278.2	263.5	1.079	.9269	176.6	634.0	457.4	.3535	.1455	118
119	282.3	267.6	1.063	.9408	177.8	634.0	456.2	.3556	.1441	119
120	286.4	271.7	1.047	0.9549	179.0	634.0	455.0	0.3576	1.1427	**120**
121	290.6	275.9	1.032	.9692	180.2	634.0	453.8	.3597	.1414	121
122	294.8	280.1	1.017	.9837	181.4	634.0	452.6	.3618	.1400	122
123	299.1	284.4	1.002	.9983	182.6	634.0	451.4	.3638	.1386	123
124	303.4	288.7	0.987	1.0132	183.9	634.0	450.1	.3659	.1372	124
125	307.8	293.1	0.973	1.028	185.1	634.0	448.9	0.3679	1.1358	**125**

EXPLANATION OF TERMS USED IN TABLES OF PROPERTIES OF SATURATED AMMONIA

(Note that these tables are based on a temperature of −40° F.

1. *Temperature in Degrees Fahrenheit.* Given in the first column is the temperature of the saturated ammonia. The properties tabulated are for saturated ammonia, and will not hold for superheated conditions. Saturated ammonia contains no liquid ammonia and has no superheat.

2. *Absolute Pressure in Pounds per Square Inch.* Absolute pressure is measured from zero. If a perfect vacuum existed, the absolute pressure would be zero.

3. *Gage Pressure in Pounds per Square Inch.* Gage pressure is measured from 14.7 lbs. abs. or, in other words, it begins at atmospheric pressure as zero.

4. *Specific Volume of the Liquid in Cubic Feet.* This column gives the number of cubic feet of ammonia liquid in one pound at this temperature.

5. *Density of Vapor.* The density of a vapor is found by dividing *one* by the number of cubic feet of the vapor in a pound at that pressure. For example, the density given in the tables for a temperature of 10° F. as 0.1369 is found by dividing 1 by 7.304, the volume given in column 4.

6. *Enthalpy or Heat Content of the Liquid.* This column gives the total heat in the liquid ammonia, assuming −40° F. as the zero from which the heat is computed.

7. *Enthalpy or Heat Content of Vapor.* This column gives the total heat of the vapor above −40° F. These values are found by adding the heat content of liquid in column 6 to the latent heat of vaporization of ammonia in column 8.

8. *Latent Heat of Vaporization of Ammonia.* This column gives the amount of heat required to vaporize the ammonia after it has been raised to its boiling point at this pressure and temperature.

9. *Entropy of the Liquid.* These values are based on the total heat of the liquid found in column 6. These are computed from above −40° F.

10. *The Entropy of the Vapor.* This includes the entropy of liquid and latent heat based on the temperature above −40° F.

To show application of this table a few simple problems will be explained.

Problem 1. What volume will 10 lbs. of ammonia occupy at 100° F.?

Computation. Referring to Table 2A-1, the volume of one pound of ammonia vapor at 100° F. is 1.419 cu. ft. Ten pounds will, therefore, occupy ten times 1.419, or 14.19 cu. ft.

Problem 2. How much heat must be extracted to lower 20 lbs. of ammonia from 80° F. to 0° F., assuming the pressure is likewise lowered?

Computation. Referring to Table 2A-1, the total heat of one pound of vapor at 80° F. is 630.7 Btu. The total heat at 0° F. is 611.8 Btu. The amount of heat it is necessary to remove from one pound will be, then, 630.7 − 611.8, or 18.9 Btu. For 20 lbs. it will be 20 × 18.9, or 378 Btu.

TABLE 2A-2. PROPERTIES OF SUPERHEATED AMMONIA

(Arranged by American Society of Refrigerating Engineers from the Bureau of Standards Tables. From A.S.R.E. Data Book)

Temp. °F.	Abs. Pressure 5 lb./in.² Gage Pressure **19.7*** (Sat'n. Temp. — 63.11° F.)			Abs. Pressure 6 lb./in.² Gage Pressure **17.7*** (Sat'n. Temp. — 57.64° F.)			Abs. Pressure 7 lb./in.² Gage Pressure **15.7*** (Sat'n. Temp. — 52.88° F)			Abs. Pressure 8 lb./in.² Gage Pressure **13.6*** (Sat'n. Temp. — 48.64° F.)		
	Volume ft.³/lb.	Heat Content Btu./lb.	Entropy Btu /lb.°F.	Volume ft.³/lb.	Heat Content Btu /lb.	Entropy Btu /lb °F	Volume ft.³/lb.	Heat Content Btu./lb.	Entropy Btu /lb.°F	Volume ft.³/lb.	Heat Content Btu /lb.	Entropy Btu./lb.°F.
t	***V***	***H***	***S***	***V***	***H***	***S***	***V***	***H***	***S***	***V***	***H***	***S***
(at sat'n)	*(49.31)*	*(588.3)*	*(1.4857)*	*(41.59)*	*(590.6)*	*(1.4703)*	*(36.01)*	*(592.7)*	*(1.4574)*	*(31.79)*	*(594.2)*	*(1.4462)*
−50	51.05	595.2	1.5025	42.44	594.6	1.4803	36.29	594.0	1.4611	....	....	....
−40	52.36	600.3	1.5149	43.55	599.8	1.4928	37.25	599.3	1.4739	32.52	598.8	1.4573
−30	53.67	605.4	1.5269	44.64	604.9	1.5049	38.19	604.5	1.4861	33.36	604.1	1.4697
−20	54.97	610.4	1.5385	45.73	610.0	1.5166	39.13	609.6	1.4979	34.19	609.3	1.4816
−10	56.26	615.4	1.5498	46.82	615.1	1.5280	40.07	614.7	1.5094	35.01	614.4	1.4932
0	57.55	620.4	1.5608	47.90	620.1	1.5391	41.00	619.8	1.5206	35.83	619.5	1.5044
10	58.84	625.4	1.5716	48.98	625.2	1.5499	41.93	624.9	1.5314	36.64	624.6	1.5154
20	60.12	630.4	1.5821	50.05	630.2	1.5605	42.85	629.9	1.5421	37.45	629.7	1.5261
30	61.41	635.4	1.5925	51.12	635.2	1.5708	43.77	635.0	1.5525	38.26	634.7	1.5365
40	62.69	640.4	1.6026	52.19	640.2	1.5810	44.69	640.0	1.5627	39.07	639.8	1.5467
50	63.96	645.5	1.6125	53.26	645.2	1.5910	45.61	645.0	1.5727	39.88	644.8	1.5568
60	65.24	650.5	1.6223	54.32	650.3	1.6008	46.53	650.1	1.5825	40.68	649.9	1.5666
70	66.51	655.5	1.6319	55.39	655.3	1.6104	47.44	655.2	1.5921	41.48	655.0	1.5763
80	67.79	660.6	1.6413	56.45	660.4	1.6199	48.36	660.2	1.6016	42.28	660.1	1.5858
90	69.06	665.6	1.6506	57.51	665.5	1.6292	49.27	665.3	1.6110	43.08	665.2	1.5952
100	70.33	670.7	1.6598	58.58	670.6	1.6384	50.18	670.4	1.6202	43.88	670.3	1.6044
110	71.60	675.8	1.6689	59.64	675.7	1.6474	51.09	675.5	1.6292	44.68	675.4	1.6135
120	72.87	680.9	1.6778	60.70	680.8	1.6563	52.00	680.7	1.6382	45.48	680.5	1.6224
130	74.14	686.1	1.6865	61.76	685.9	1.6651	52.91	685.8	1.6470	46.27	685.7	1.6312
140	75.41	691.2	1.6952	62.82	691.1	1.6738	53.82	691.0	1.6557	47.07	690.9	1.6399
150	76.68	696.4	1.7038	63.87	696.3	1.6824	54.73	696.2	1.6643	47.87	696.1	1.6485
160	77.95	701.6	1.7122	64.93	701.5	1.6909	55.63	701.4	1.6727	48.66	701.3	1.6570
170	79.21	706.8	1.7206	65.99	706.7	1.6992	56.54	706.6	1.6811	49.46	706.5	1.6654
180	80.48	712.1	1.7289	67.05	712.0	1.7075	57.45	711.9	1.6894	50.25	711.8	1.6737

Temp. °F.	Abs. Pressure 9 lb./in.² Gage Pressure **11.6*** (Sat'n. Temp. — 44.38° F.)			Abs. Pressure 10 lb./in.² Gage Pressure **9.6*** (Sat'n. Temp. — 41.34° F.)			Abs. Pressure 11 lb./in.² Gage Pressure **7.5*** (Sat'n. Temp. — 38.14° F.)			Abs. Pressure 12 lb./in.² Gage Pressure **5.5*** (Sat'n. Temp. — 35.16° F.)		
(at sat'n)	*(28.45)*	*(595.7)*	*(1.4363)*	*(25.81)*	*(597.1)*	*(1.4276)*	*(23.61)*	*(598.3)*	*(1.4196)*	*(21.77)*	*(599.4)*	*(1.4124)*
−40	28.85	598.3	1.4426	25.90	597.8	1.4293	......	......	......	......	......	......
−30	29.59	603.6	1.4551	26.58	603.2	1.4420	24.12	602.7	1.4300	22.07	602.3	1.4190
−20	30.34	603.9	1.4672	27.26	608.5	1.4542	24.74	608.1	1.4423	22.64	607.7	1.4314
−10	31.07	614.0	1.4788	27.92	613.7	1.4659	25.35	613.3	1.4542	23.20	613.0	1.4434
0	31.80	619.2	1.4902	28.58	618.9	1.4773	25.95	618.5	1.4656	23.75	618.2	1.4549
10	32.53	624.3	1.5012	29.24	624.0	1.4884	26.55	623.7	1.4768	24.31	623.4	1.4661
20	33.26	629.4	1.5119	29.90	629.1	1.4992	27.15	628.9	1.4876	24.86	628.6	1.4770
30	33.98	634.5	1.5224	30.55	634.2	1.5097	27.74	634.0	1.4982	25.41	633.7	1.4877
40	34.70	639.5	1.5327	31.20	639.3	1.5200	28.34	639.1	1.5085	25.95	638.9	1.4980
50	35.42	644.6	1.5427	31.85	644.4	1.5301	28.93	644.2	1.5187	26.49	644.0	1.5082
60	36.13	649.7	1.5526	32.49	649.5	1.5400	29.52	649.3	1.5286	27.03	649.1	1.5182
70	36.85	654.8	1.5623	33.14	654.6	1.5497	30.10	654.4	1.5383	27.57	654.3	1.5279
80	37.56	659.9	1.5718	33.78	659.7	1.5593	30.69	659.6	1.5479	28.11	659.4	1.5375
90	38.27	665.0	1.5812	34.42	664.8	1.5687	31.28	664.7	1.5573	28.65	664.5	1.5470
100	38.98	670.1	1.5904	35.07	670.0	1.5779	31.86	669.8	1.5666	29.19	669.7	1.5562
110	39.70	675.3	1.5995	35.71	675.1	1.5870	32.44	675.0	1.5757	29.72	674.8	1.5654
120	40.40	680.4	1.6085	36.35	680.3	1.5960	33.03	680.1	1.5847	30.26	680.0	1.5744
130	41.11	685.6	1.6173	36.99	685.4	1.6049	33.61	685.3	1.5936	30.79	685.2	1.5833
140	41.82	690.7	1.6260	37.62	690.6	1.6136	34.19	690.5	1.6023	31.33	690.4	1.5920
150	42.53	695.9	1.6346	38.26	695.8	1.6222	34.77	695.7	1.6109	31.86	695.6	1.6006
160	43.24	701.2	1.6431	38.90	701.1	1.6307	35.35	700.9	1.6194	32.39	700.8	1.6092
170	43.95	706.4	1.6515	39.54	706.3	1.6391	35.93	706.2	1.6278	32.92	706.1	1.6176
180	44.65	711.7	1.6598	40.17	711.6	1.6474	36.51	711.5	1.6362	33.46	711.4	1.6259
190	45.36	716.9	1.6680	40.81	716.9	1.6556	37.09	716.8	1.6444	33.99	716.7	1.6341
200	46.07	722.2	1.6761	41.45	722.2	1.6637	37.67	722.1	1.6525	34.52	722.0	1.6422

* Inches of mercury at 32° F. below one standard atmosphere (29.92 in. = 14,696 lbs. abs.).

TABLE 2A-2. PROPERTIES OF SUPERHEATED AMMONIA (*Continued*)

(*Arranged by American Society of Refrigerating Engineers from the Bureau of Standards Tables. From A.S.R.E. Data Book*)

Temp. °F.	Abs. Pressure 13 lb./in.² Gage Pressure 3.5* (Sat'n. Temp. — 32.37° F.)			Abs. Pressure 14 lb./in.² Gage Pressure 1.4* (Sat'n. Temp. — 29.76° F.)			Abs. Pressure 15 lb./in.² Gage Pressure 0.3 lb./in.² (Sat'n. Temp. — 27.29° F.)			Abs. Pressure 16 lb./in.² Gage Pressure 1.3 lb./in.² (Sat'n. Temp. — 24.95° F.)		
t	*V*	*H*	*S*	*V*	*H*	*S*	*V*	*H*	*S*	*V*	*H*	*S*
(*at sat'n*)	(*20.20*)	(*600.5*)	(*1.4057*)	(*18.85*)	(*601.4*)	(*1.3996*)	(*17.67*)	(*602.4*)	(*1.3938*)	(*16.65*)	(*603.2*)	(*1.3885*)
−30	20.33	601.8	1.4088	......	......	......	......	......	......	......	......	......
−20	20.86	607.2	1.4213	19.33	606.8	1.4119	18.01	606.4	1.4031	16.86	606.0	1.3948
−10	21.38	612.6	1.4334	19.82	612.2	1.4241	18.47	611.9	1.4154	17.29	611.5	1.4072
0	21.90	617.9	1.4450	20.30	617.6	1.4358	18.92	617.2	1.4272	17.72	616.9	1.4191
10	22.41	623.1	1.4563	20.78	622.8	1.4472	19.37	622.5	1.4386	18.14	622.2	1.4306
20	22.92	628.3	1.4672	21.26	628.0	1.4582	19.82	627.8	1.4497	18.56	627.5	1.4417
30	23.43	633.5	1.4779	21.73	633.2	1.4688	20.26	633.0	1.4604	18.97	632.7	1.4525
40	23.93	638.6	1.4883	22.20	638.4	1.4793	20.70	638.2	1.4709	19.39	638.0	1.4630
50	24.43	643.8	1.4985	22.67	643.6	1.4896	21.14	643.4	1.4812	19.80	643.2	1.4733
60	24.94	648.9	1.5085	23.14	648.7	1.4996	21.58	643.5	1.4912	20.21	648.3	1.4834
70	25.43	654.1	1.5183	23.60	653.9	1.5094	22.01	653.7	1.5011	20.62	653.5	1.4933
80	25.93	659.2	1.5279	24.06	659.0	1.5191	22.44	658.9	1.5108	21.03	658.7	1.5030
90	26.43	664.4	1.5374	24.53	664.2	1.5285	22.88	664.0	1.5203	21.43	663.9	1.5125
100	26.93	669.5	1.5467	24.99	669.4	1.5378	23.31	669.2	1.5296	21.84	669.1	1.5218
110	27.42	674.7	1.5558	25.45	674.5	1.5470	23.74	674.4	1.5388	22.24	674.3	1.5310
120	27.92	679.9	1.5649	25.91	679.7	1.5560	24.17	679.6	1.5478	22.65	679.5	1.5401
130	28.41	685.1	1.5737	26.37	684.9	1.5649	24.60	684.8	1.5567	23.05	684.7	1.5490
140	28.90	690.3	1.5825	26.83	690.1	1.5737	25.03	690.0	1.5355	23.45	689.9	1.5578
150	29.40	695.5	1.5911	27.29	695.4	1.5824	25.46	695.3	1.5742	23.86	695.1	1.5665
160	29.89	700.7	1.5997	27.74	700.6	1.5909	25.88	700.5	1.5827	24.26	700.4	1.5750
170	30.38	706.0	1.6081	28.20	705.9	1.5993	26.31	705.8	1.5911	24.66	705.7	1.5835
180	30.87	711.3	1.6164	28.66	711.2	1.6076	26.74	711.1	1.5995	25.06	711.0	1.5918
190	31.36	716.6	1.6246	29.11	716.5	1.6159	27.16	716.4	1.6077	25.46	716.3	1.6001
200	31.85	721.9	1.6328	29.57	721.8	1.6240	27.59	721.7	1.6158	25.86	721.6	1.6082
210	32.34	727.2	1.6408	30.02	727.1	1.6320	28.02	727.0	1.6239	26.26	727.0	1.6163
220	32.83	732.6	1.6487	30.48	732.5	1.6400	28.44	732.4	1.6318	26.66	732.3	1.6242
230	33.32	738.0	1.6566	30.94	737.9	1.6478	28.88	737.8	1.6397	27.05	737.7	1.6321
240	33.81	743.4	1.6644	31.39	743.3	1.6556	29.29	743.2	1.6475	27.45	743.1	1.6399
250	34.30	748.8	1.6721	31.84	748.7	1.6633	29.71	748.6	1.6552	27.85	748.6	1.6476

Temp. °F.	Abs. Pressure 17 lb./in.² Gage Pressure 2.3 lb./in.² (Sat'n. Temp. — 22.73° F.)			Abs. Pressure 18 lb./in.² Gage Pressure 3.3 lb./in.² (Sat'n. Temp. — 20.61° F.)			Abs. Pressure 19 lb./in.² Gage Pressure 4.3 lb./in.² (Sat'n. Temp. — 18.58° F.)			Abs. Pressure 20 lb./in.² Gage Pressure 5.3 lb./in.² (Sat'n. Temp. — 16.34° F.)		
(at sat'n)	*(15.72)*	*(604.0)*	*(1.3835)*	*(14.90)*	*(604.8)*	*(1.3787)*	*(14.17)*	*(605.5)*	*(1.3742)*	*(13.50)*	*(606.3)*	*(1.3700)*
−20	15.83	605.6	1.3870	14.93	605.1	1.3795	......	......	......	......	......	......
−10	16.24	611.1	1.3994	15.32	610.7	1.3921	14.49	610.3	1.3851	13.74	610.0	1.3784
0	16.65	616.6	1.4114	15.70	616.2	1.4042	14.85	615.9	1.3973	14.09	615.5	1.3907
10	17.05	621.9	1.4230	16.08	621.6	1.4158	15.21	621.3	1.4090	14.44	621.0	1.4025
20	17.45	627.2	1.4342	16.46	626.9	1.4270	15.57	626.7	1.4203	14.78	626.4	1.4138
30	17.84	632.5	1.4450	16.83	632.2	1.4380	15.93	632.0	1.4312	15.11	631.7	1.4248
40	18.23	637.7	1.4556	17.20	637.5	1.4486	16.28	637.3	1.4419	15.45	637.0	1.4356
50	18.62	642.9	1.4659	17.57	642.7	1.4590	16.63	642.5	1.4523	15.78	642.3	1.4460
60	19.01	648.1	1.4761	17.94	647.9	1.4691	16.98	647.7	1.4625	16.12	647.5	1.4562
70	19.39	653.3	1.4860	18.30	653.1	1.4790	17.33	653.0	1.4724	16.45	652.8	1.4662
80	19.78	658.5	1.4957	18.67	658.4	1.4887	17.67	658.2	1.4822	16.78	658.0	1.4760
90	20.16	663.7	1.5052	19.03	663.6	1.4983	18.02	663.4	1.4918	17.10	663.2	1.4856
100	20.54	668.9	1.5146	19.39	668.8	1.5077	18.36	668.6	1.5012	17.43	668.5	1.4950
110	20.92	674.1	1.5238	19.75	674.0	1.5169	18.70	673.8	1.5104	17.76	673.7	1.5042
120	21.30	679.3	1.5328	20.11	679.2	1.5260	19.04	679.1	1.5195	18.08	678.9	1.5133
130	21.68	684.5	1.5418	20.47	684.4	1.5349	19.38	684.3	1.5285	18.41	684.2	1.5223
140	22.06	689.8	1.5506	20.83	689.7	1.5438	19.72	689.5	1.5373	18.73	689.4	1.5312
150	22.44	695.0	1.5593	21.19	694.9	1.5525	20.06	694.8	1.5460	19.05	694.7	1.5399
160	22.82	700.3	1.5678	21.54	700.2	1.5610	20.40	700.1	1.5546	19.37	700.0	1.5485
170	23.20	705.6	1.5763	21.90	705.5	1.5695	20.74	705.4	1.5631	19.70	705.3	1.5569
180	23.58	710.9	1.5846	22.26	710.8	1.5778	21.08	710.7	1.5714	20.02	710.6	1.5653
190	23.95	716.2	1.5929	22.61	716.1	1.5861	21.42	716.0	1.5797	20.34	715.9	1.5736
200	24.33	721.5	1.6010	22.97	721.4	1.5943	21.75	721.3	1.5878	20.66	721.2	1.5817
210	24.71	726.9	1.6091	23.33	726.8	1.6023	22.09	726.7	1.5959	20.98	726.6	1.5898
220	25.08	732.2	1.6170	23.68	732.2	1.6103	22.43	732.1	1.6039	21.30	732.0	1.5978
230	25.46	737.6	1.6249	24.04	737.6	1.6182	22.77	737.5	1.6118	21.62	737.4	1.6057
240	25.83	743.1	1.6327	24.39	743.0	1.6260	23.10	742.9	1.6196	21.94	742.8	1.6135
250	26.21	748.5	1.6405	24.75	748.4	1.6337	23.44	748.4	1.6273	22.26	748.3	1.6212

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* Inches of mercury at 32° F. below one standard atmosphere (29.92 in. = 14.696 lbs. abs.).

TABLE 2A-2. PROPERTIES OF SUPERHEATED AMMONIA (*Continued*)

(*Arranged by American Society of Refrigerating Engineers from the Bureau of Standards Tables. From A.S.R.E. Data Book*)

Temp. °F.	Abs. Pressure 21 lb./in.^{2} Gage Pressure 6.3 lb./in.^{2} (Sat'n. Temp. — 14.78° F.)			Abs. Pressure 22 lb./in.^{2} Gage Pressure 7.3 lb./in.^{2} (Sat'n Temp. — 12.98° F.)			Abs. Pressure 23 lb./in.^{2} Gage Pressure 8.3 lb./in.^{2} (Sat'n. Temp. — 11.25° F.)			Abs. Pressure 24 lb./in.^{2} Gage Pressure 9.3 lb./in.^{2} (Sat'n Temp. — 9.58° F.)		
t	*V*	*H*	*S*	*V*	*H*	*S*	*V*	*H*	*S*	*V*	*H*	*S*
(*at sat'n*)	(*12.90*)	(*606.8*)	(*1.3659*)	(*12.35*)	(*607.4*)	(*1.3621*)	(*11.85*)	(*608.1*)	(*1.3584*)	(*11.39*)	(*608.6*)	(*1.3545*)
−10	13.06	609.6	1.3720	12.45	609.2	1.3659	11.89	608.8	1.3600	......	......	......
0	13.40	615.2	1.3844	12.77	614.8	1.3784	12.20	614.5	1.3726	11.67	614.1	1.3670
10	13.73	620.7	1.3962	13.09	620.4	1.3903	12.50	620.0	1.3846	11.96	619.7	1.3791
20	14.06	626.1	1.4077	13.40	625.8	1.4018	12.80	625.5	1.3961	12.25	625.2	1.3907
30	14.38	631.5	1.4187	13.71	631.2	1.4129	13.10	630.9	1.4073	12.54	630.7	1.4019
40	14.70	636.8	1.4295	14.02	636.6	1.4237	13.40	636.3	1.4181	12.82	636.1	1.4128
50	15.02	642.1	1.4400	14.32	641.9	1.4342	13.69	641.6	1.4287	13.11	641.4	1.4234
60	15.34	647.3	1.4502	14.63	647.1	1.4445	13.98	646.9	1.4390	13.39	646.7	1.4337
70	15.65	652.6	1.4602	14.93	652.4	1.4545	14.27	652.2	1.4491	13.66	652.0	1.4438
80	15.97	657.8	1.4700	15.23	657.7	1.4643	14.56	657.5	1.4589	13.94	657.3	1.4537
90	16.28	663.1	1.4796	15.53	662.9	1.4740	14.84	662.7	1.4686	14.22	662.6	1.4634
100	16.59	668.3	1.4891	15.83	668.1	1.4834	15.13	668.0	1.4780	14.49	667.8	1.4729
110	16.90	673.5	1.4983	16.12	673.4	1.4927	15.41	673.2	1.4873	14.76	673.1	1.4822
120	17.21	678.8	1.5075	16.42	678.6	1.5019	15.70	678.5	1.4955	15.04	678.4	1.4914
130	17.52	684.0	1.5165	16.72	683.9	1.5109	15.98	683.8	1.5055	15.31	683.6	1.5004
140	17.83	689.3	1.5253	17.01	689.2	1.5197	16.26	689.0	1.5144	15.58	688.9	1.5093
150	18.14	694.6	1.5340	17.31	694.4	1.5285	16.55	694.3	1.5231	15.85	694.2	1.5180
160	18.44	699.8	1.5426	17.60	699.7	1.5371	16.83	699.6	1.5317	16.12	699.5	1.5266
170	18.75	705.1	1.5510	17.89	705.0	1.5456	17.11	704.9	1.5402	16.39	704.8	1.5352
180	19.06	710.5	1.5595	18.19	710.4	1.5539	17.39	710.3	1.5486	16.66	710.2	1.5436
190	19.36	715.8	1.5678	18.48	715.7	1.5622	17.67	715.6	1.5569	16.93	715.5	1.5518
200	19.67	721.1	1.5759	18.77	721.1	1.5704	17.95	721.0	1.5651	17.20	720.9	1.5600
210	19.98	726.5	1.5840	19.06	726.4	1.5785	18.23	726.4	1.5732	17.46	726.3	1.5681
220	20.28	731.9	1.5920	19.35	731.8	1.5865	18.51	731.7	1.5812	17.73	731.7	1.5761
230	20.59	737.3	1.5999	19.65	737.2	1.5944	18.79	737.2	1.5891	18.00	737.1	1.5841
240	20.89	742.7	1.6077	19.94	742.7	1.6022	19.07	742.6	1.5969	18.27	742.6	1.5919
250	21.20	748.2	1.6155	20.23	748.1	1.6100	19.34	748.1	1.6047	18.53	748.0	1.5996
260	21.50	753.7	1.6231	20.52	753.6	1.6176	19.62	753.5	1.6123	18.80	753.4	1.6073
270	21.80	759.2	1.6307	20.81	759.1	1.6252	19.90	759.0	1.6199	19.07	759.0	1.6149

Temp. °F.	Abs. Pressure 25 lb./in.^{2} Gage Pressure 10.3 lb./in.^{2} (Sat'n. Temp. — 7.96° F.)			Abs. Pressure 26 lb./in.^{2} Gage Pressure 11.3 lb./in.^{2} (Sat'n Temp. — 6.39° F.)			Abs. Pressure 27 lb./in.^{2} Gage Pressure 12.3 lb./in.^{2} (Sat'n. Temp. — 4.87° F.)			Abs. Pressure 28 lb./in.^{2} Gage Pressure 13.3 lb./in.^{2} (Sat'n. Temp. — 3.40° F.)		
(at sat'n)	*(10.96)*	*(609.1)*	*(1.3515)*	*(10.56)*	*(609.7)*	*(1.3482)*	*(10.20)*	*(610.2)*	*(1.3451)*	*(9.853)*	*(610.7)*	*(1.3421)*
0	11.19	613.8	1.3616	10.74	613.4	1.3564	10.33	613.0	1.3513	9.94	612.7	1.3465
10	11.47	619.4	1.3738	11.01	619.1	1.3686	10.59	618.8	1.3637	10.20	618.4	1.3589
20	11.75	625.0	1.3855	11.28	624.7	1.3804	10.85	624.4	1.3755	10.45	624.1	1.3708
30	12.03	630.4	1.3967	11.55	630.2	1.3917	11.11	629.9	1.3869	10.70	629.6	1.3822
40	12.30	635.8	1.4077	11.81	635.6	1.4027	11.37	635.4	1.3979	10.95	635.1	1.3933
50	12.57	641.2	1.4183	12.08	641.0	1.4134	11.62	640.8	1.4087	11.19	640.5	1.4041
60	12.84	646.5	1.4287	12.34	646.3	1.4238	11.87	646.1	1.4191	11.44	645.9	1.4145
70	13.11	651.8	1.4388	12.59	651.6	1.4339	12.12	651.5	1.4292	11.68	651.2	1.4247
80	13.37	657.1	1.4487	12.85	656.9	1.4439	12.37	656.8	1.4392	11.92	656.6	1.4347
90	13.64	662.4	1.4584	13.11	662.2	1.4536	12.61	662.1	1.4489	12.15	661.9	1.4445
100	13.90	667.7	1.4679	13.36	667.5	1.4631	12.86	667.4	1.4585	12.39	667.2	1.4540
110	14.17	673.0	1.4772	13.61	672.8	1.4725	13.10	672.7	1.4679	12.63	672.5	1.4634
120	14.43	678.2	1.4864	13.87	678.1	1.4817	13.34	678.0	1.4771	12.86	677.8	1.4726
130	14.69	683.5	1.4954	14.12	683.4	1.4907	13.59	683.3	1.4861	13.10	683.1	1.4817
140	14.95	688.8	1.5043	14.37	688.7	1.4996	13.83	688.6	1.4950	13.33	688.4	1.4906
150	15.21	694.1	1.5131	14.62	694.0	1.5084	14.07	693.9	1.5038	13.56	693.7	1.4994
160	15.47	699.4	1.5217	14.87	699.3	1.5170	14.31	699.2	1.5125	13.80	699.1	1.5081
170	15.73	704.7	1.5303	15.12	704.6	1.5256	14.55	704.5	1.5210	14.03	704.4	1.5167
180	15.99	710.1	1.5387	15.37	710.0	1.5340	14.79	709.9	1.5295	14.26	709.8	1.5251
190	16.25	715.4	1.5470	15.62	715.3	1.5423	15.03	715.2	1.5378	14.49	715.1	1.5334
200	16.50	720.8	1.5552	15.86	720.7	1.5505	15.27	720.6	1.5460	14.72	720.5	1.5416
210	16.76	726.2	1.5633	16.11	726.1	1.5586	15.51	726.0	1.5541	14.95	725.9	1.5497
220	17.02	731.6	1.5713	16.36	731.5	1.5666	15.75	731.4	1.5621	15.18	731.3	1.5578
230	17.27	737.0	1.5792	16.61	736.9	1.5745	15.99	736.8	1.5700	15.41	736.8	1.5657
240	17.53	742.5	1.5870	16.85	742.4	1.5824	16.23	742.3	1.5779	15.64	742.2	1.5736
250	17.79	747.9	1.5948	17.10	747.8	1.5901	16.46	742.8	1.5856	15.87	747.7	1.5813
260	18.04	753.4	1.6025	17.35	753.3	1.5978	16.70	753.2	1.5933	16.10	753.2	1.5890
270	18.30	758.9	1.6101	17.59	758.8	1.6054	16.94	758.8	1.6009	16.33	758.7	1.5966

TABLE 2A–2. PROPERTIES OF SUPERHEATED AMMONIA (*Continued*)

(*Arranged by American Society of Refrigerating Engineers from the Bureau of Standards Tables. From A.S.R.E. Data Book*)

Temp. °F.	Abs. Pressure 29 lb./in.² Gage Pressure 14.3 lb./in.² (Sat'n. Temp. − 1.97° F.)			Abs. Pressure 30 lb./in.² Gage Pressure 15.3 lb./in.² (Sat'n. Temp. − 0.57° F.)			Abs. Pressure 31 lb./in.² Gage Pressure 16.3 lb./in.² (Sat'n. Temp. + 0.79° F.)			Abs. Pressure 32 lb./in.² Gage Pressure 17.3 lb./in.² (Sat'n. Temp. + 2.11° F.)		
t	*V*	*H*	*S*	*V*	*H*	*S*	*V*	*H*	*S*	*V*	*H*	*S*
(at sat'n)	(*9.534*)	(*611.1*)	(*1.3392*)	(*9.236*)	(*611.6*)	(*1.3364*)	(*8.965*)	(*612.0*)	(*1.3336*)	(*8.693*)	(*612.4*)	(*1.3310*)
0	9.584	612.3	1.3417	9.250	611.9	1.3371	......	......	......	......	......	......
10	9.834	618.1	1.3542	9.492	617.8	1.3497	9.173	617.4	1.3453	8.874	617.1	1.3411
20	10.08	623.8	1.3362	9.731	623.5	1.3618	9.405	623.2	1.3574	9.099	622.9	1.3532
30	10.32	629.4	1.3777	9.966	629.1	1.3733	9.633	628.8	1.3691	9.321	628.5	1.3649
40	10.56	634.9	1.3888	10.20	634.6	1.3845	9.858	634.4	1.3803	9.540	634.1	1.3762
50	10.80	640.3	1.3996	10.43	640.1	1.3953	10.08	639.9	1.3912	9.757	639.6	1.3871
60	11.03	645.7	1.4101	10.65	645.5	1.4059	10.30	645.3	1.4017	9.972	645.1	1.3977
70	11.26	651.1	1.4204	10.88	650.9	1.4161	10.52	650.7	1.4120	10.18	650.5	1.4080
80	11.50	656.4	1.4304	11.10	656.2	1.4261	10.74	656.1	1.4221	10.40	655.9	1.4181
90	11.73	661.7	1.4401	11.33	661.6	1.4359	10.96	661.4	1.4319	10.61	661.2	1.4280
100	11.96	667.1	1.4497	11.55	666.9	1.4456	11.17	666.7	1.4415	10.81	666.6	1.4376
110	12.18	672.4	1.4591	11.77	672.2	1.4550	11.38	672.1	1.4510	11.02	671.9	1.4470
120	12.41	677.7	1.4684	11.99	677.5	1.4642	11.60	677.4	1.4602	11.23	677.3	1.4563
130	12.64	683.0	1.4775	12.21	682.9	1.4733	11.81	682.7	1.4693	11.44	682.6	1.4655
140	12.86	688.3	1.4864	12.43	688.2	1.4823	12.02	688.1	1.4783	11.64	687.9	1.4744
150	13.09	693.6	1.4952	12.65	693.5	1.4911	12.23	693.4	1.4871	11.85	693.3	1.4833
160	13.31	699.0	1.5039	12.87	698.8	1.4998	12.44	698.7	1.4958	12.05	698.6	1.4920
170	13.54	704.3	1.5124	13.08	704.2	1.5083	12.66	704.1	1.5044	12.26	704.0	1.5006
180	13.76	709.7	1.5209	13.30	709.6	1.5168	12.87	709.5	1.5129	12.46	709.4	1.5090
190	13.99	715.0	1.5292	13.52	714.9	1.5251	13.07	714.8	1.5212	12.66	714.7	1.5174
200	14.21	720.4	1.5374	13.73	720.3	1.5334	13.28	720.2	1.5294	12.86	720.1	1.5256
210	14.43	725.8	1.5455	13.95	725.7	1.5415	13.49	725.6	1.5376	13.07	725.6	1.5338
220	14.65	731.2	1.5536	14.16	731.1	1.5495	13.70	731.1	1.5456	13.27	731.0	1.5418
230	14.88	736.7	1.5615	14.38	736.6	1.5575	13.91	736.5	1.5536	13.47	736.4	1.5498
240	15.10	742.2	1.5694	14.59	742.0	1.5653	14.12	742.0	1.5614	13.67	741.9	1.5576
250	15.32	747.6	1.5772	14.81	747.5	1.5732	14.32	747.4	1.5692	13.87	747.4	1.5654
260	15.54	753.1	1.5848	15.02	753.0	1.5808	14.53	752.9	1.5769	14.08	752.9	1.5731
270	15.76	758.6	1.5925	15.23	758.5	1.5884	14.74	758.5	1.5845	14.28	758.4	1.5808
280	15.98	764.1	1.6000	15.45	764.1	1.5960	14.95	764.0	1.5921	14.48	763.9	1.5883

Temp. °F.	Abs. Pressure 33 lb./in.^{2} Gage Pressure 18.3 lb./in.^{2} (Sat'n. Temp. 3.40° F.)			Abs. Pressure 34 lb./in.^{2} Gage Pressure 19.3 lb./in.^{2} (Sat'n. Temp. 4.66° F.)			Abs. Pressure 35 lb./in.^{2} Gage Pressure 20.3 lb./in.^{2} (Sat'n. Temp. 5.89° F.)			Abs. Pressure 36 lb./in.^{2} Gage Pressure 21.3 lb./in.^{2} (Sat'n. Temp. 7.00° F.)		
(sat'n)	*(8.445)*	*(612.8)*	*(1.3285)*	*(8.211)*	*(613.2)*	*(1.3260)*	*(7.991)*	*(613.6)*	*(1.3236)*	*(7.782)*	*(614.0)*	*(1.3213)*
10	8.592	616.8	1.3369	8.328	616.4	1.3328	8.078	616.1	1.3289	7.842	615.7	1.3250
20	8.812	622.6	1.3492	8.542	622.3	1.3452	8.287	622.0	1.3413	8.016	621.7	1.3375
30	9.028	628.3	1.3609	8.753	628.0	1.3570	8.493	627.7	1.3532	8.247	627.4	1.3494
40	9.242	633.9	1.3722	8.960	633.6	1.3684	8.695	633.4	1.3646	8.445	633.1	1.3609
50	9.452	639.4	1.3832	9.166	639.2	1.3793	8.895	638.9	1.3756	8.640	638.7	1.3720
60	9.661	644.9	1.3938	9.369	644.7	1.3900	9.093	644.4	1.3863	8.833	644.2	1.3827
70	9.868	650.3	1.4042	9.570	650.1	1.4004	9.289	649.9	1.3967	9.024	649.7	1.3932
80	10.07	655.7	1.4143	9.770	655.5	1.4105	9.484	655.3	1.4069	9.214	655.2	1.4033
90	10.28	661.1	1.4241	9.969	660.9	1.4204	9.677	660.7	1.4168	9.402	660.6	1.4133
100	10.48	666.4	1.4338	10.17	666.3	1.4301	9.869	666.1	1.4265	9.589	666.0	1.4230
110	10.68	671.8	1.4433	10.36	671.6	1.4396	10.06	671.5	1.4360	9.775	671.3	1.4325
120	10.88	677.1	1.4526	10.56	677.0	1.4489	10.25	676.8	1.4453	9.961	676.7	1.4419
130	11.08	682.5	1.4617	10.75	682.3	1.4581	10.44	682.2	1.4545	10.15	682.1	1.4510
140	11.28	687.8	1.4707	10.95	687.7	1.4671	10.63	687.6	1.4635	10.33	687.4	1.4601
150	11.48	693.2	1.4795	11.14	693.0	1.4759	10.82	692.9	1.4724	10.51	692.8	1.4689
160	11.68	698.5	1.4883	11.33	698.4	1.4846	11.00	698.3	1.4811	10.69	698.2	1.4777
170	11.88	703.9	1.4968	11.53	703.8	1.4932	11.19	703.7	1.4897	10.88	703.6	1.4863
180	12.08	709.3	1.5053	11.72	709.2	1.5017	11.38	709.1	1.4982	11.06	709.0	1.4948
190	12.27	714.6	1.5137	11.91	714.5	1.5101	11.56	714.5	1.5066	11.24	714.4	1.5032
200	12.47	720.0	1.5219	12.10	720.0	1.5183	11.75	719.9	1.5148	11.42	719.8	1.5115
210	12.67	725.5	1.5301	12.29	725.4	1.5265	11.94	725.3	1.5230	11.60	725.2	1.5196
220	12.86	730.9	1.5381	12.48	730.8	1.5346	12.12	730.7	1.5311	11.78	730.6	1.5277
230	13.06	736.4	1.5461	12.67	736.3	1.5425	12.31	736.2	1.5390	11.96	736.1	1.5357
240	13.26	741.8	1.5540	12.86	741.7	1.5504	12.49	741.7	1.5469	12.14	741.6	1.5436
250	13.45	747.3	1.5618	13.05	747.2	1.5582	12.68	747.2	1.5547	12.32	747.1	1.5514
260	13.65	752.8	1.5695	13.24	752.7	1.5659	12.86	752.7	1.5624	12.50	752.6	1.5591
270	13.84	758.3	1.5771	13.43	758.3	1.5737	13.04	758.2	1.5701	12.68	758.1	1.5667
280	14.04	763.9	1.5846	13.62	763.8	1.5811	13.23	763.7	1.5776	12.86	763.7	1.5743

TABLE 2A-2. PROPERTIES OF SUPERHEATED AMMONIA (*Continued*)

(*Arranged by American Society of Refrigerating Engineers from the Bureau of Standards Tables. From A.S.R.E. Data Book*)

Temp. °F.	Abs. Pressure 37 lb./in.² Gage Pressure 22.3 lb./in.² (Sat'n. Temp. 8.27° F.)			Abs. Pressure 38 lb./in.² Gage Pressure 23.3 lb./in.² (Sat'n. Temp. 9.42° F.)			Abs. Pressure 39 lb./in.² Gage Pressure 24.3 lb./in.² (Sat'n. Temp. 10.55° F.)			Abs. Pressure 40 lb./in.² Gage Pressure 25.3 lb./in.² (Sat'n. Temp. 11.66° F.)		
t	*V*	*H*	*S*	*V*	*H*	*S*	*V*	*H*	*S*	*V*	*H*	*S*
(at sat'n)	(*7.584*)	(*614.3*)	(*1.3190*)	(*7.396*)	(*614.7*)	(*1.3168*)	(*7.217*)	(*615.0*)	(*1.3146*)	(*7.047*)	(*615.4*)	(*1.3125*)
10	7.619	615.4	1.3212	7.407	615.0	1.3175	......	......	......	......	......	......
20	7.819	621.4	1.3338	7.603	621.0	1.3301	7.398	620.7	1.3266	7.203	620.4	1.3231
30	8.015	627.2	1.3458	7.795	626.9	1.3422	7.586	626.6	1.3387	7.387	626.3	1.3353
40	8.208	632.9	1.3573	7.983	632.6	1.3538	7.770	632.4	1.3504	7.568	632.1	1.3470
50	8.398	638.5	1.3684	8.170	638.3	1.3650	7.952	638.0	1.3616	7.746	637.8	1.3583
60	8.587	644.0	1.3792	8.353	643.8	1.3758	8.132	643.6	1.3724	7.922	643.4	1.3692
70	8.773	649.5	1.3897	8.535	649.3	1.3863	8.310	649.1	1.3830	8.096	648.9	1.3797
80	8.958	655.0	1.3999	8.716	654.8	1.3965	8.486	654.6	1.3932	8.268	654.4	1.3900
90	9.142	660.4	1.4098	8.895	660.2	1.4065	8.661	660.1	1.4032	8.439	659.9	1.4000
100	9.324	665.8	1.4196	9.073	665.6	1.4163	8.835	665.5	1.4130	8.609	665.3	1.4098
110	9.506	671.2	1.4291	9.250	671.0	1.4258	9.008	670.9	1.4226	8.777	670.7	1.4194
120	9.686	676.6	1.4385	9.426	676.4	1.4352	9.179	676.3	1.4320	8.945	676.1	1.4288
130	9.866	681.9	1.4477	9.602	681.8	1.4444	9.351	681.7	1.4412	9.112	681.5	1.4381
140	10.05	687.3	1.4567	9.776	687.2	1.4534	9.521	687.1	1.4503	9.278	686.9	1.4471
150	10.22	692.7	1.4656	9.950	692.6	1.4623	9.691	692.5	1.4592	9.444	692.3	1.4561
160	10.40	698.1	1.4744	10.12	698.0	1.4711	9.860	697.8	1.4679	9.609	697.7	1.4648
170	10.58	703.5	1.4830	10.30	703.3	1.4797	10.03	703.2	1.4766	9.774	703.1	1.4735
180	10.76	708.9	1.4915	10.47	708.7	1.4883	10.20	708.6	1.4851	9.938	708.5	1.4820
190	10.93	714.3	1.4999	10.64	714.2	1.4966	10.36	714.1	1.4935	10.10	714.0	1.4904
200	11.11	719.7	1.5082	10.81	719.6	1.5049	10.53	719.5	1.5018	10.27	719.4	1.4987
210	11.28	725.1	1.5163	10.98	725.0	1.5131	10.70	724.9	1.5100	10.43	724.9	1.5069
220	11.46	730.6	1.5244	11.16	730.5	1.5212	10.87	730.4	1.5181	10.59	730.3	1.5150
230	11.63	736.0	1.5324	11.33	735.9	1.5292	11.03	735.9	1.5261	10.75	735.8	1.5230
240	11.81	741.5	1.5403	11.50	741.4	1.5371	11.20	741.3	1.5340	10.92	741.3	1.5309
250	11.98	747.0	1.5481	11.67	746.9	1.5449	11.36	746.9	1.5418	11.08	746.8	1.5387
260	12.16	752.5	1.5558	11.84	752.4	1.5526	11.53	752.4	1.5495	11.24	752.3	1.5465
270	12.33	758.1	1.5634	12.01	758.0	1.5602	11.70	757.9	1.5572	11.40	757.8	1.5541
280	12.51	763.6	1.5710	12.18	763.5	1.5678	11.86	763.5	1.5647	11.56	763.4	1.5617

Temp. °F.	Abs. Pressure 42 lb./in.^{2} Gage Pressure 27.3 lb./in.^{2} (Sat'n. Temp. 13.81° F.)			Abs. Pressure 44 lb./in.^{2} Gage Pressure 29.3 lb./in.^{2} (Sat'n. Temp. 15.88° F.)			Abs. Pressure 46 lb./in.^{2} Gage Pressure 31.3 lb./in.^{2} (Sat'n. Temp. 17.87° F.)			Abs. Pressure 48 lb./in.^{2} Gage Pressure 33.3 lb./in.^{2} (Sat'n. Temp. 19.80° F.)		
(at sat'n)	*(6.731)*	*(616.0)*	*(1.3084)*	*(6.448)*	*(616.6)*	*(1.3046)*	*(6.177)*	*(617.2)*	*(1.3009)*	*(5.934)*	*(617.7)*	*(1.2975)*
20	6.842	619.8	1.3164	6.513	619.1	1.3099	6.213	618.5	1.3036	5.937	617.8	1.2976
30	7.019	625.8	1.3287	6.683	625.2	1.3224	6.377	624.6	1.3162	6.096	624.0	1.3103
40	7.192	631.6	1.3405	6.850	631.1	1.3343	6.538	630.5	1.3283	6.251	630.0	1.3225
50	7.363	637.3	1.3519	7.014	636.8	1.3457	6.696	636.4	1.3398	6.404	635.9	1.3341
60	7.531	643.0	1.3628	7.176	642.5	1.3567	6.851	642.1	1.3509	6.554	641.6	1.3453
70	7.697	648.5	1.3734	7.336	648.1	1.3674	7.005	647.7	1.3617	6.702	647.3	1.3561
80	7.862	654.1	1.3838	7.494	653.7	1.3778	7.157	653.3	1.3721	6.848	652.9	1.3666
90	8.026	659.5	1.3939	7.650	659.2	1.3880	7.308	658.9	1.3823	6.993	658.5	1.3768
100	8.188	665.0	1.4037	7.806	664.7	1.3978	7.457	664.4	1.3922	7.137	664.0	1.3868
110	8.349	670.4	1.4133	7.960	670.1	1.4075	7.605	669.8	1.4019	7.280	669.5	1.3965
120	8.510	675.9	1.4228	8.114	675.6	1.4170	7.753	675.3	1.4114	7.421	675.0	1.4061
130	8.669	681.3	1.4320	8.267	681.0	1.4263	7.899	680.7	1.4207	7.562	680.5	1.4154
140	8.828	686.7	1.4411	8.419	686.4	1.4354	8.045	686.2	1.4299	7.702	685.9	1.4246
150	8.986	692.1	1.4501	8.570	691.9	1.4444	8.190	691.6	1.4389	7.842	691.4	1.4336
160	9.144	697.5	1.4589	8.721	697.3	1.4532	8.335	697.1	1.4477	7.981	696.8	1.4425
170	9.301	702.9	1.4676	8.871	702.7	1.4619	8.479	702.5	1.4564	8.119	702.3	1.4512
180	9.458	708.3	1.4761	9.021	708.1	1.4704	8.623	707.9	1.4650	8.257	707.7	1.4598
190	9.614	713.8	1.4845	9.171	713.6	1.4789	8.766	713.4	1.4735	8.395	713.2	1.4683
200	9.770	719.2	1.4928	9.320	719.0	1.4872	8.909	718.8	1.4818	8.532	718.7	1.4766
210	9.926	724.7	1.5010	9.468	724.5	1.4954	9.051	724.3	1.4900	8.669	724.1	1.4849
220	10.08	730.1	1.5091	9.617	730.0	1.5035	9.194	729.8	1.4981	8.805	729.6	1.4930
230	10.24	735.6	1.5170	9.765	735.5	1.5115	9.335	735.3	1.5062	8.941	735.1	1.5011
240	10.39	741.1	1.5251	9.913	741.0	1.5195	9.477	740.8	1.5141	9.077	740.6	1.5090
250	10.54	746.6	1.5329	10.06	746.5	1.5273	9.618	746.3	1.5220	9.213	746.2	1.5168
260	10.70	752.2	1.5406	10.21	752.0	1.5350	9.760	751.9	1.5297	9.348	751.7	1.5246
270	10.85	757.7	1.5483	10.36	757.6	1.5427	9.900	757.4	1.5374	9.483	757.3	1.5323
280	11.01	763.3	1.5559	10.50	763.1	1.5503	10.04	763.0	1.5450	9.619	762.9	1.5399
290	11.16	768.9	1.5633	10.65	768.7	1.5578	10.18	768.6	1.5525	9.753	768.5	1.5474
300	11.31	774.5	1.5708	10.80	774.3	1.5652	10.32	774.2	1.5599	9.888	774.1	1.5548

TABLE 2A-2. PROPERTIES OF SUPERHEATED AMMONIA (*Continued*)

(*Arranged by American Society of Refrigerating Engineers from the Bureau of Standards Tables. From A.S.R.E. Data Book*)

Temp. °F.	Abs. Pressure 50 lb./in.^{2} Gago Pressure 35.3 lb./in.^{2} (Sat'n. Temp. 21.67° F.)			Abs. Pressure 52 lb./in.^{2} Gage Pressure 37.3 lb./in.^{2} (Sat'n. Temp. 23.48° F.)			Abs. Pressure 54 lb./in.^{2} Gage Pressure 39.3 lb./in.^{2} (Sat'n. Temp. 25 23° F.)			Abs. Pressure 56 lb./in.^{2} Gage Pressure 41.3 lb./in.^{2} (Sat'n. Temp. 26.94° F.)		
t	*V*	*H*	*S*	*V*	*H*	*S*	*V*	*H*	*S*	*V*	*H*	*S*
(satur'n)	(*5.710*)	(*618.2*)	(*1.2959*)	(*5.502*)	(*618.7*)	(*1.2906*)	(*5.309*)	(*619.2*)	(*1.2876*)	(*5.129*)	(*619.7*)	(*1.2844*)
30	5.838	623.4	1.3046	5.599	622.8	1.2991	5.378	622.2	1.2937	5.172	621.6	1.2884
40	5.988	629.5	1.3169	5.744	629.0	1.3114	5.519	628.4	1.3062	5.310	627.9	1.3011
50	6.135	635.4	1.3286	5.887	634.9	1.3233	5.657	634.4	1.3181	5.444	633.9	1.3131
60	6.280	641.2	1.3399	6.027	640.8	1.3346	5.793	640.3	1.3295	5.576	639.9	1.3248
70	6.423	646.9	1.3508	6.165	646.5	1.3456	5.927	646.1	1.3408	5.706	645.7	1.3357
80	6.564	652.6	1.3613	6.302	652.2	1.3562	6.059	651.8	1.3513	5.834	651.4	1.3465
90	6.704	658.2	1.3716	6.437	657.8	1.3665	6.190	657.5	1.3616	5.960	657.1	1.3569
100	6.843	663.7	1.3816	6.571	663.4	1.3766	6.319	663.1	1.3717	6.085	662.7	1.3670
110	6.980	669.2	1.3914	6.704	668.9	1.3864	6.447	668.6	1.3816	6.209	668.3	1.3769
120	7.117	674.7	1.4009	6.835	674.4	1.3960	5.575	674.2	1.3912	6.333	673.9	1.3866
130	7.252	680.2	1.4103	6.966	679.9	1.4054	6.701	679.7	1.4006	6.455	679.4	1.3961
140	7.387	685.7	1.4195	7.096	685.4	1.4146	6.827	685.2	1.4099	6.576	684.9	1.4053
150	7.521	691.1	1.4286	7.225	690.9	1.4237	6.952	690.7	1.4190	6.697	690.4	1.4144
160	7.655	696.6	1.4374	7.354	696.4	1.4326	7.076	696.1	1.4279	6.817	695.9	1.4234
170	7.788	702.1	1.4462	7.483	701.8	1.4413	7.200	701.6	1.4367	6.937	701.4	1.4322
180	7.921	707.5	1.4548	7.611	707.3	1.4500	7.323	707.1	1.4453	7.056	706.9	1.4408
190	8.053	713.0	1.4633	7.738	712.8	1.4585	7.446	712.6	1.4538	7.175	712.4	1.4494
200	8.185	718.5	1.4716	7.865	718.3	1.4668	7.569	718.1	1.4622	7.294	717.9	1.4578
210	8.317	724.0	1.4799	7.992	723.8	1.4751	7.691	723.6	1.4705	7.412	723.4	1.4661
220	8.448	729.4	1.4880	8.118	729.3	1.4833	7.813	729.1	1.4787	7.529	728.9	1.4743
230	8.579	735.0	1.4961	8.244	734.8	1.4913	7.934	734.6	1.4867	7.647	734.5	1.4823
240	8.710	740.5	1.5040	8.370	740.3	1.4993	8.056	740.2	1.4947	7.764	740.0	1.4903
250	8.840	746.0	1.5119	8.496	745.9	1.5072	8.177	745.7	1.5026	7.881	745.6	1.4982
260	8.970	751.6	1.5197	8.621	751.4	1.5149	8.298	751.3	1.5104	7.998	751.1	1.5060
270	9.100	757.2	1.5274	8.746	757.0	1.5227	8.418	756.9	1.5182	8.114	756.7	1.5137
280	9.230	762.7	1.5350	8.871	762.6	1.5303	8.539	762.5	1.5257	8.230	762.3	1.5213
290	9.360	768.4	1.5425	8.996	768.2	1.5378	8.659	768.1	1.5332	8.346	768.0	1.5289
300	9.489	774.0	1.5500	9.120	773.8	1.5453	8.779	773.7	1.5407	8.462	773.6	1.5364
310	9.618	779.6	1.5574	9.245	779.5	1.5527	8.899	779.4	1.5481	8.578	779.3	1.5438

Temp. °F.	Abs. Pressure 58 lb./in.² Gage Pressure 43.3 lb./in.² (Sat'n. Temp. 28.59° F.)			Abs. Pressure 60 lb./in.² Gage Pressure 45.3 lb./in.² (Sat'n. Temp. 30.21° F.)			Abs. Pressure 62 lb./in.² Gage Pressure 47.3 lb./in.² (Sat'n. Temp. 31.78° F.)			Abs. Pressure 64 lb./in.² Gage Pressure 49.3 lb./in.² (Sat'n. Temp. 33.31° F.)		
(at sat'n)	*(4.968)*	*(620.1)*	*(1.2816)*	*(4.805)*	*(620.5)*	*(1.2787)*	*(4.658)*	*(620.9)*	*(1.2759)*	*(4.519)*	*(621.3)*	*(1.2730)*
30	4.981	621.0	1.2834	......	......	......	......	......	......	......	......	......
40	5.115	627.3	1.2961	4.933	626.8	1.2913	4.762	626.2	1.2866	4.602	625.6	1.2820
50	5.245	633.4	1.3082	5.060	632.9	1.3035	4.886	632.4	1.2989	4.723	631.9	1.2944
60	5.373	639.4	1.3199	5.184	639.0	1.3152	5.007	638.5	1.3107	4.842	638.0	1.3063
70	5.499	645.3	1.3310	5.307	644.9	1.3265	5.127	644.4	1.3220	4.958	644.0	1.3177
80	5.624	651.1	1.3418	5.428	650.7	1.3373	5.244	650.3	1.3330	5.072	649.9	1.3287
90	5.746	656.8	1.3523	5.547	656.4	1.3479	5.360	656.0	1.3435	5.185	655.7	1.3393
100	5.868	662.4	1.3625	5.665	662.1	1.3581	5.474	661.7	1.3538	5.296	661.4	1.3496
110	5.988	668.0	1.3724	5.781	667.7	1.3681	5.588	667.4	1.3638	5.406	667.1	1.3597
120	6.107	673.6	1.3821	5.897	673.3	1.3778	5.700	673.0	1.3736	5.516	672.7	1.3695
130	6.226	679.1	1.3916	6.012	678.9	1.3873	5.811	678.6	1.3831	5.624	678.3	1.3791
140	6.343	684.7	1.4009	6.126	684.4	1.3966	5.922	684.2	1.3925	5.731	683.9	1.3885
150	6.460	690.2	1.4100	6.239	689.9	1.4058	6.032	689.7	1.4017	5.838	689.5	1.3977
160	6.577	695.7	1.4190	6.352	695.5	1.4148	6.142	695.2	1.4107	5.944	695.0	1.4067
170	6.692	701.2	1.4278	6.464	701.0	1.4236	6.250	700.8	1.4195	6.050	700.5	1.4156
180	6.808	706.7	1.4365	6.576	706.5	1.4323	6.359	706.3	1.4282	6.155	706.1	1.4243
190	6.923	712.2	1.4450	6.687	712.0	1.4409	6.467	711.8	1.4368	6.260	711.6	1.4329
200	7.037	717.7	1.4535	6.798	717.5	1.4493	6.574	717.3	1.4453	6.364	717.2	1.4413
210	7.151	723.2	1.4618	6.909	723.1	1.4576	6.681	722.9	1.4536	6.468	722.7	1.4497
220	7.265	728.8	1.4700	7.019	728.6	1.4658	6.788	728.4	1.4618	6.572	728.3	1.4579
230	7.379	734.3	1.4781	7.129	734.1	1.4739	6.895	734.0	1.4699	6.675	733.8	1.4660
240	7.492	739.9	1.4860	7.238	739.7	1.4819	7.001	739.5	1.4779	6.778	739.4	1.4741
250	7.605	745.4	1.4939	7.348	745.3	1.4898	7.107	745.1	1.4859	6.881	745.0	1.4820
260	7.718	751.0	1.5017	7.457	750.9	1.4976	7.213	750.7	1.4937	6.984	750.6	1.4898
270	7.830	756.6	1.5094	7.566	756.5	1.5053	7.318	756.3	1.5014	7.086	756.2	1.4975
280	7.943	762.2	1.5171	7.675	762.1	1.5130	7.424	761.9	1.5091	7.188	761.8	1.5052
290	8.055	767.8	1.5246	7.783	767.7	1.5206	7.529	767.6	1.5166	7.291	767.4	1.5128
300	8.167	773.5	1.5321	7.892	773.3	1.5281	7.634	773.2	1.5241	7.392	773.1	1.5203
310	8.279	779.1	1.5396	8.000	779.0	1.5355	7.739	778.9	1.5316	7.494	778.8	1.5277

TABLE 2A-2. PROPERTIES OF SUPERHEATED AMMONIA (*Continued*)

(*Arranged by American Society of Refrigerating Engineers from the Bureau of Standards Tables. From A.S.R.E. Data Book*)

Temp °F.	Abs. Pressure 66 lb./in.² Gage Pressure 51.3 lb./in.² (Sat'n. Temp. 34.81° F.)			Abs. Pressure 68 lb./in.² Gage Pressure 53.3 lb./in.² (Sat'n. Temp. 36.27° F.)			Abs. Pressure 70 lb./in.² Gage Pressure 55.3 lb./in.² (Sat'n. Temp. 37.70° F.)			Abs. Pressure 75 lb./in.² Gage Pressure 60.3 lb./in.² (Sat'n. Temp. 41.13° F.)		
t	*V*	*H*	*S*	*V*	*H*	*S*	*V*	*H*	*S*	*V*	*H*	*S*
(at sat'n)	(*4.385*)	(*621.7*)	(*1.2707*)	(*4.267*)	(*622.0*)	(*1.2682*)	(*4.151*)	(*622.4*)	(*1.2658*)	(*3.887*)	(*623.2*)	(*1.2599*)
40	4.452	625.1	1.2775	4.310	624.5	1.2731	4.177	623.9	1.2688	......	......	......
50	4.570	631.4	1.2900	4.426	630.9	1.2858	4.290	630.4	1.2816	3.982	629.1	1.2715
60	4.636	637.6	1.3020	4.539	637.1	1.2978	4.401	636.6	1.2937	4.087	635.5	1.2839
70	4.739	643.6	1.3135	4.650	643.2	1.3094	4.509	642.7	1.3054	4.189	641.7	1.2957
80	4.910	649.5	1.3245	4.758	649.1	1.3205	4.615	648.7	1.3166	4.289	647.7	1.3071
90	5.020	655.3	1.3352	4.865	655.0	1.3312	4.719	654.6	1.3274	4.388	653.7	1.3180
100	5.120	661.1	1.3456	4.971	660.7	1.3417	4.822	660.4	1.3378	4.485	659.6	1.3286
110	5.236	666.8	1.3557	5.075	663.5	1.3518	4.924	666.1	1.3480	4.581	665.4	1.3389
120	5.312	672.4	1.3655	5.179	672.1	1.3617	5.025	671.8	1.3579	4.676	671.1	1.3489
130	5.447	678.0	1.3751	5.281	677.8	1.3713	5.125	677.5	1.3676	4.770	676.8	1.3586
140	5.552	683.6	1.3846	5.383	683.4	1.3807	5.224	683.1	1.3770	4.863	682.5	1.3682
150	5.656	689.2	1.3938	5.484	689.0	1.3900	5.323	688.7	1.3863	4.956	688.1	1.3775
160	5.759	694.8	1.4028	5.585	694.5	1.3991	5.420	694.3	1.3954	5.048	693.7	1.3866
170	5.862	700.3	1.4117	5.685	700.1	1.4080	5.518	699.9	1.4043	5.139	699.3	1.3956
180	5.964	705.9	1.4205	5.784	705.7	1.4167	5.615	705.5	1.4131	5.230	704.9	1.4044
190	6.066	711.4	1.4291	5.883	711.2	1.4254	5.711	711.0	1.4217	5.320	710.5	1.4131
200	6.167	717.0	1.4375	5.982	716.8	1.4338	5.807	716.6	1.4302	5.410	716.1	1.4217
210	6.268	722.5	1.4459	6.080	722.3	1.4422	5.902	722.2	1.4386	5.500	721.7	1.4301
220	6.369	728.1	1.4541	6.179	727.9	1.4505	5.998	727.7	1.4469	5.589	727.3	1.4384
230	6.470	733.7	1.4623	6.275	733.5	1.4586	6.093	733.3	1.4550	5.678	732.9	1.4466
240	6.570	739.2	1.4703	6.373	739.1	1.4666	6.187	738.9	1.4631	5.767	738.5	1.4546
250	6.669	744.8	1.4782	6.470	744.7	1.4746	6.281	744.5	1.4711	5.855	744.1	1.4625
260	6.769	750.4	1.4861	6.567	750.3	1.4824	6.376	750.1	1.4789	5.943	749.8	1.4705
270	6.868	756.0	1.4935	6.663	755.9	1.4902	6.470	755.8	1.4866	6.031	755.4	1.4783
280	6.968	761.7	1.5015	6.760	761.5	1.4979	6.563	761.4	1.4943	6.119	761.1	1.4860
290	7.067	767.3	1.5091	6.856	767.2	1.5055	6.657	767.1	1.5019	6.206	766.7	1.4936
300	7.165	773.0	1.5166	6.952	772.8	1.5130	6.750	772.7	1.5095	6.294	772.4	1.5011
310	7.264	778.7	1.5240	7.048	778.5	1.5204	6.844	778.4	1.5169	6.381	778.1	1.5086
320	7.363	784.3	1.5314	7.143	784.2	1.5278	6.937	784.1	1.5243	6.468	783.8	1.5159

Temp. °F.	Abs. Pressure 80 lb./in.^{2} Gage Pressure 65.3 lb./in.^{2} (Sat'n. Temp. 44.40° F.)			Abs. Pressure 85 lb./in.^{2} Gage Pressure 70.3 lb./in.^{2} (Sat'n. Temp. 47.30° F.)			Abs. Pressure 90 lb./in.^{2} Gage Pressure 75.3 lb./in.^{2} (Sat'n. Temp. 50.47° F.)			Abs. Pressure 95 lb./in.^{2} Gage Pressure 80.3 lb./in.^{2} (Sat'n. Temp. 53.32° F.)		
(at sat'r)	*(3.656)*	*(624.0)*	*(1.2346)*	*(3.449)*	*(624.7)*	*(1.2494)*	*(3.266)*	*(625.3)*	*(1.2446)*	*(3.101)*	*(625.9)*	*(1.2399)*
50	3.712	627.7	1.2619	3.473	626.4	1.2527	......	......	......	......	......	......
60	3.812	634.3	1.2745	3.569	633.0	1.2656	3.353	631.8	1.2571	3.160	630.5	1.2489
70	3.909	640.6	1.2866	3.662	639.5	1.2779	3.442	638.3	1.2695	3.245	637.2	1.2616
80	4.005	646.7	1.2981	3.753	645.7	1.2896	3.529	644.7	1.2814	3.329	643.6	1.2736
90	4.098	652.8	1.3092	3.842	651.8	1.3008	3.614	650.9	1.2928	3.411	649.9	1.2852
100	4.190	658.7	1.3199	3.930	657.8	1.3117	3.698	657.0	1.3038	3.491	656.1	1.2963
110	4.281	664.6	1.3303	4.016	663.8	1.3221	3.780	663.0	1.3144	3.570	662.1	1.3070
120	4.371	670.4	1.3404	4.101	669.6	1.3323	3.862	668.9	1.3247	3.647	668.1	1.3174
130	4.460	676.1	1.3502	4.186	675.4	1.3422	3.942	674.7	1.3347	3.724	674.0	1.3275
140	4.548	681.8	1.3598	4.269	681.2	1.3519	4.021	680.5	1.3444	3.799	679.8	1.3373
150	4.635	687.5	1.3692	4.352	686.9	1.3614	4.100	686.3	1.3539	3.874	685.6	1.3469
160	4.722	693.2	1.3784	4.434	692.6	1.3706	4.178	692.0	1.3633	3.949	691.4	1.3562
170	4.808	698.8	1.3874	4.515	698.2	1.3797	4.255	697.7	1.3724	4.022	697.1	1.3654
180	4.893	704.4	1.3963	4.596	703.9	1.3886	4.332	703.4	1.3813	4.096	702.8	1.3744
190	4.978	710.0	1.4050	4.677	709.5	1.3974	4.408	709.0	1.3901	4.168	708.5	1.3833
200	5.063	715.6	1.4136	4.757	715.2	1.4060	4.484	714.7	1.3988	4.241	714.2	1.3919
210	5.147	721.3	1.4220	4.836	720.8	1.4145	4.560	720.4	1.4073	4.313	719.9	1.4005
220	5.231	726.9	1.4304	4.916	726.4	1.4228	4.635	726.0	1.4157	4.384	725.6	1 4089
230	5.315	732.5	1.4386	4.995	732.1	1.4311	4.710	731.7	1.4239	4.455	731.3	1.4172
240	5.398	738.1	1.4467	5.074	737.7	1.4392	4.785	737.3	1.4321	4.526	736.9	1.4254
250	5.482	743.8	1.4547	5.152	743.4	1.4472	4.859	743.0	1.4401	4.597	742.6	1.4334
260	5.565	749.4	1.4626	5.230	749.0	1.4551	4.933	748.7	1.4481	4.668	748.3	1.4414
270	5.647	755.1	1.4704	5.308	754.7	1.4629	5.007	754.4	1.4559	4.738	754.0	1.4492
280	5.730	760.7	1.4781	5.386	760.4	1.4707	5.081	760.0	1.4637	4.808	759.7	1.4570
290	5.812	766.4	1.4857	5.464	766.1	1.4783	5.155	765.8	1.4713	4.878	765.4	1.4647
300	5.894	772.1	1.4933	5.541	771.8	1.4859	5.228	771.5	1.4789	4.947	771.2	1.4723
310	5.976	777.8	1.5008	5.619	777.5	1.4934	5.301	777.2	1.4864	5.017	776.9	1.4798
320	6.058	783.5	1.5081	5.696	783.2	1.5008	5.374	783.0	1.4938	5.086	782.7	1.4873

TABLE 2A-2. PROPERTIES OF SUPERHEATED AMMONIA (*Continued*)

(*Arranged by American Society of Refrigerating Engineers from the Bureau of Standards Tables. From A.S.R.E. Data Book*)

Temp. °F.	Abs. Pressure 100 lb./in.² Gage Pressure 85.3 lb./in.² (Sat'n. Temp. 56.05° F.)			Abs. Pressure 105 lb./in.² Gage Pressure 90.3 lb./in.² (Sat'n. Temp. 58.67° F.)			Abs. Pressure 110 lb./in.² Gage Pressure 95.3 lb./in.² (Sat'n. Temp 61.21° F.)			Abs. Pressure 115 lb./in.² Gage Pressure 100.3 lb./in.² (Sat'n. Temp. 63.56° F.)		
t	*V*	*H*	*S*	*V*	*H*	*S*	*V*	*H*	*S*	*V*	*H*	*S*
(*at sat'n*)	(*2.952*)	(*626.5*)	(*1.2356*)	(*2.817*)	(*627.0*)	(*1.2314*)	(*2.693*)	(*627.5*)	(*1.2275*)	(*2.580*)	(*628.0*)	(*1.2237*)
60	2.985	629.3	1.2409	......	......	......	......	......	......	......	......	......
70	3.068	636.0	1.2539	2.907	634.9	1.2464	2.761	633.7	1.2392	2.628	632.5	1.2323
80	3.149	642.6	1.2661	2.985	641.5	1.2589	2.837	640.5	1.2519	2.701	639.4	1.2451
90	3.227	649.0	1.2778	3.061	648.0	1.2708	2.910	647.0	1.2640	2.772	646.0	1.2574
100	3.304	655.2	1.2891	3.135	654.3	1.2822	2.981	653.4	1.2755	2.841	652.5	1.2690
110	3.380	661.3	1.2999	3.208	660.5	1.2931	3.051	659.7	1.2866	2.909	658.8	1.2802
120	3.454	667.3	1.3104	3.279	666.6	1.3037	3.120	665.8	1.2972	2.975	665.0	1.2910
130	3.527	673.3	1.3206	3.350	672.6	1.3139	3.188	671.9	1.3076	3.040	671.1	1.3015
140	3.600	679.2	1.3305	3.419	678.5	1.3239	3.255	677.8	1.3176	3.105	677.2	1.3116
150	3.672	685.0	1.3401	3.488	684.4	1.3336	3.321	683.7	1.3274	3.168	683.1	1.3215
160	3.743	690.8	1.3495	3.556	690.2	1.3431	3.386	689.6	1.3370	3.231	689.0	1.3311
170	3.813	696.6	1.3588	3.623	696.0	1.3524	3.451	695.4	1.3463	3.294	694.9	1.3405
180	3.883	702.3	1.3678	3.690	701.8	1.3615	3.515	701.2	1.3555	3.355	700.7	1.3497
190	3.952	708.0	1.3767	3.757	707.5	1.3704	3.579	707.0	1.3644	3.417	706.5	1.3587
200	4.021	713.7	1.3854	3.823	713.3	1.3792	3.642	712.8	1.3732	3.477	712.3	1.3675
210	4.090	719.4	1.3940	3.888	719.0	1.3878	3.705	718.5	1.3819	3.538	718.1	1.3762
220	4.158	725.1	1.4024	3.954	724.7	1.3963	3.768	724.3	1.3904	3.598	723.8	1.3847
230	4.226	730.8	1.4108	4.019	730.4	1.4046	3.830	730.0	1.3988	3.658	729.6	1.3931
240	4.294	736.5	1.4190	4.083	736.1	1.4129	3.892	735.7	1.4070	3.717	735.3	1.4014
250	4.361	742.2	1.4271	4.148	741.9	1.4210	3.954	741.5	1.4151	3.776	741.1	1.4096
260	4.428	747.9	1.4350	4.212	747.6	1.4290	4.015	747.2	1.4232	3.835	746.8	1.4176
270	4.495	753.6	1.4429	4.276	753.3	1.4369	4.076	752.9	1.4311	3.894	752.6	1.4256
280	4.562	759.4	1.4507	4.340	759.0	1.4447	4.137	758.7	1.4389	3.952	758.4	1.4334
290	4.629	765.1	1.4584	4.403	764.8	1.4524	4.198	764.5	1.4466	4.011	764.1	1.4411
300	4.695	770.8	1.4660	4.466	770.5	1.4600	4.259	770.2	1.4543	4.069	769.9	1.4488
310	4.761	776.6	1.4736	4.529	776.3	1.4676	4.319	776.0	1.4619	4.127	775.7	1.4564
320	4.827	732.4	1.4810	4.593	782.1	1.4750	4.379	781.8	1.4693	4.185	781.5	1.4639
330	4.893	788.2	1.4884	4.655	787.9	1.4824	4.439	787.6	1.4767	4.242	787.3	1.4713
340	4.959	794.0	1.4957	4.718	793.7	1.4897	4.500	793.4	1.4841	4.300	793.1	1.4786
350	5.024	799.8	1.5029	4.781	799.5	1.4969	4.559	799.3	1.4859	4.357	799.0	1.4859

Temp °F.	Abs. Pressure 120 lb /in.² Gage Pressure 105.3 lb./in.² (Sat'n. Temp. 66 02° F.)			Abs. Pressure 125 lb /in.² Gage Pressure 110.3 lb./in.² (Sat'n. Temp. 68.31° F.)			Abs. Pressure 130 lb /in.² Gage Pressure 115.3 lb./in.² (Sat'n. Temp. 70.53° F.)			Abs. Pressure 135 lb /in.² Gage Pressure 120.3 lb./in.² (Sat'n. Temp. 72.69° F.)		
(sat'n)	*(2.476)*	*(628.4)*	*(1.2201)*	*(2.380)*	*(628.8)*	*(1.2166)*	*(2.291)*	*(629.2)*	*(1.2132)*	*(2.209)*	*(629.6)*	*(1.2100)*
70	2.505	631.3	1.2255	2.392	630.0	1.2189	......	......	....	......	......	....
80	2.576	638.3	1.2386	2.461	637.2	1.2322	2.355	636.0	1.2260	2.257	634.9	1.2199
90	2.645	645.0	1.2510	2.528	644.0	1.2448	2.421	643.0	1.2388	2.321	642.0	1.2329
100	2.712	651.6	1.2628	2.593	650.7	1.2568	2.484	649.7	1.2509	2 382	648.8	1.2452
110	2.778	658.0	1.2741	2.657	657.1	1.2682	2.546	656.3	1.2625	2.442	655.4	1.2569
120	2.842	664.2	1.2850	2.719	663.5	1.2792	2.606	662.7	1.2736	2.501	661.9	1.2681
130	2.905	670.4	1.2956	2.780	669.7	1.2899	2.665	668.9	1.2843	2.559	668.2	1.2790
140	2.967	676.5	1.3058	2.840	675.8	1.3002	2.724	675.1	1.2947	2.615	674.4	1.2894
150	3.029	682.5	1.3157	2.900	681.8	1.3102	2.781	681.2	1.3048	2.671	680.5	1.2996
160	3.089	688.4	1.3254	2.958	687.8	1.3199	2.838	687.2	1.3146	2.726	686.6	1.3094
170	3.149	694.3	1.3348	3.016	693.7	1.3294	2.894	693.2	1.3241	2.780	692.6	1.3191
180	3.209	700.2	1.3441	3.074	699.6	1.3387	2.949	699.1	1.3335	2.834	698.6	1.3284
190	3.268	706.0	1.3531	3.131	705.5	1.3478	3.004	705.0	1.3426	2.887	704.5	1.3376
200	3.326	711.8	1.3620	3.187	711.3	1.3567	3.059	710.9	1.3516	2.940	710.4	1.3466
210	3.385	717.6	1.3707	3.243	717.2	1.3654	3.113	716.7	1.3604	2.992	716.2	1.3554
220	3.442	723.4	1.3793	3.299	723.0	1.3740	3.167	722.5	1.3690	3.044	722.1	1.3641
230	3.500	729.2	1.3877	3.354	728.8	1.3825	3.220	728.3	1.3775	3.096	727.9	1.3726
240	3.557	734.9	1.3960	3.409	734.5	1.3908	3.273	734.1	1.3858	3.147	733.7	1.3810
250	3.614	740.7	1.4042	3.464	740.3	1.3990	3.326	739.9	1.3941	3.198	739.6	1.3893
260	3.671	746.5	1.4123	3.519	746.1	1.4071	3.379	745.7	1.4022	3.249	745.4	1.3974
270	3.727	752.2	1.4202	3.573	751.9	1.4151	3.431	751.5	1.4102	3.300	751.2	1.4054
280	3.783	758.0	1.4281	3.627	757.7	1.4230	3.483	757.3	1.4181	3.350	757.0	1.4133
290	3.839	763.8	1.4359	3.681	763.5	1.4308	3.535	763.1	1.4259	3.400	762.8	1.4212
300	3 895	769.6	1.4435	3.735	769.3	1.4385	3.587	769.0	1.4336	3.450	768.6	1.4289
310	3.951	775.4	1.4511	3.738	775.1	1.4461	3.639	774.8	1.4412	3.500	774.4	1.4365
320	4.006	781.2	1.4586	3 842	780.9	1.4536	3.690	780.6	1.4487	3.550	780.3	1.4441
330	4.061	787.0	1.4660	3.895	786.8	1.4610	3.742	786.5	1.4562	3.599	786.2	1.4515
340	4.117	792.9	1.4734	3.948	792.6	1.4684	3.793	792.3	1.4636	3.649	792.0	1.4589
350	4.172	798.7	1.4807	4.001	798.5	1.4757	3.844	798.2	1.4709	3.698	797.9	1.4062

TABLE 2A-2. PROPERTIES OF SUPERHEATED AMMONIA (*Continued*)

(Arranged by American Society of Refrigerating Engineers from the Bureau of Standards Tables. From A.S.R.E. Data Book)

Temp. °F.	Abs. Pressure 140 lb./in.² Gage Pressure 125.3 lb./in.² (Sat'n. Temp. 74.79° F.)			Abs. Pressure 145 lb./in.² Gage Pressure 130.3 lb./in.² (Sat'n. Temp. 76.83° F.)			Abs. Pressure 150 lb./in.² Gage Pressure 135.3 lb./in.² (Sat'n. Temp. 78.81° F.)			Abs. Pressure 155 lb./in.² Gage Pressure 140.3 lb./in.² (Sat'n. Temp. 80.75° F.)		
t	*V*	*H*	*S*	*V*	*H*	*S*	*V*	*H*	*S*	*V*	*H*	*S*
(at sat'n)	*(2.132)*	*(629.9)*	*(1.2068)*	*(2.061)*	*(630.2)*	*(1.2038)*	*(1.994)*	*(630.5)*	*(1.2009)*	*(1.931)*	*(630.8)*	*(1.1980)*
80	2.166	633.8	1.2140	2.080	632.6	1.2082	2.001	631.4	1.2025	......	......	....
90	2.228	640.9	1.2272	2.141	639.9	1.2216	2.061	638.8	1.2161	1.985	637.7	1.2108
100	2.288	647.8	1.2396	2.200	646.9	1.2342	2.118	645.9	1.2289	2.041	644.9	1.2237
110	2.347	654.5	1.2515	2.257	653.6	1.2462	2.174	652.8	1.2410	2.096	651.9	1.2360
120	2.404	661.1	1.2628	2.313	660.2	1.2577	2.228	659.4	1.2526	2.149	658.6	1.2477
130	2.460	667.4	1.2738	2.368	666.7	1.2687	2.281	665.9	1.2638	2.201	665.2	1.2590
140	2.515	673.7	1.2843	2.421	673.0	1.2793	2.334	672.3	1.2745	2.252	671.6	1.2698
150	2.569	679.9	1.2945	2.474	679.2	1.2896	2.385	678.6	1.2849	2.302	677.9	1.2803
160	2.622	686.0	1.3045	2.526	685.4	1.2996	2.435	684.8	1.2949	2.351	684.2	1.2904
170	2.675	692.0	1.3141	2.577	691.4	1.3093	2.485	690.9	1.3047	2.399	690.3	1.3002
180	2.727	698.0	1.3236	2.627	697.5	1.3188	2.534	696.9	1.3142	2.447	696.3	1.3098
190	2.779	704.0	1.3328	2.677	703.4	1.3281	2.583	702.9	1.3236	2.494	702.4	1.3192
200	2.830	709.9	1.3418	2.727	709.4	1.3372	2.631	708.9	1.3327	2.541	708.4	1.3283
210	2.880	715.8	1.3507	2.776	715.3	1.3461	2.679	714.8	1.3416	2.587	714.3	1.3373
220	2.931	721.6	1.3594	2.825	721.2	1.3548	2.726	720.7	1.3504	2.633	720.3	1.3461
230	2.981	727.5	1.3679	2.873	727.1	1.3634	2.773	726.6	1.3590	2.679	726.2	1.3548
240	3.030	733.3	1.3763	2.921	732.9	1.3718	2.820	732.5	1.3675	2.725	732.1	1.3633
250	3.080	739.2	1.3846	2.969	738.8	1.3801	2.866	738.4	1.3758	2.770	738.0	1.3716
260	3.129	745.0	1.3928	3.017	744.6	1.3883	2.912	744.3	1.3840	2.815	743.9	1.3798
270	3.179	750.8	1.4008	3.064	750.5	1.3964	2.958	750.1	1.3921	2.860	749.8	1.3879
280	3.227	756.7	1.4088	3.111	756.3	1.4043	3.004	756.0	1.4001	2.904	755.7	1.3960
290	3.275	762.5	1.4166	3.158	762.2	1.4122	3.049	761.8	1.4079	2.948	761.5	1.4038
300	3.323	768.3	1.4243	3.205	768.0	1.4199	3.095	767.7	1.4157	2.991	767.4	1.4116
310	3.371	774.2	1.4320	3.252	773.9	1.4276	3.140	773.6	1.4234	3.035	773.3	1.4193
320	3.420	780.0	1.4395	3.298	779.7	1.4352	3.185	779.4	1.4310	3.079	779.2	1.4269
330	3.467	785.9	1.4470	3.344	785.6	1.4427	3.230	785.3	1.4385	3.122	785.1	1.4344
340	3.515	791.8	1.4544	3.391	791.5	1.4501	3.274	791.2	1.4459	3.166	791.0	1.4419
350	3.563	797.7	1.4617	3.437	717.4	1.4574	3.319	797.1	1.4532	3.209	796.9	1.4492
360	3.610	803.6	1.4690	3.483	803.3	1.4647	3.364	803.0	1.4605	3.252	802.8	1.4565

Temp. °F	Abs. Pressure 160 lb./in.² Gage Pressure 145.3 lb./in.² (Sat'n. Temp 82.64° F.)			Abs. Pressure 165 lb./in.² Gage Pressure 150.3 lb./in.² (Sat'n. Temp. 84.49° F.)			Abs. Pressure 170 lb./in.² Gage Pressure 155.3 lb./in.² (Sat'n. Temp. 86.29° F.)			Abs. Pressure 175 lb./in.² Gage Pressure 160.3 lb./in.² (Sat'n. Temp. 88.06° F.)		
(at sat'n)	*(1.872)*	*(631 1)*	*(1.1952)*	*(1.816)*	*(631.4)*	*(1.1926)*	*(1.764)*	*(631.6)*	*(1.1900)*	*(1.715)*	*(631.8)*	*(1.1874)*
90	1 914	636 6	1.2055	1.847	635.5	1.2003	1.784	634.4	1.1952	1.725	633.3	1.1902
100	1 969	643 9	1.2186	1.901	642.9	1.2136	1.837	641.9	1.2087	1.777	640.9	1.2039
110	2.023	651.0	1.2311	1.954	650.1	1.2263	1.889	649.1	1.2215	1.828	648.2	1.2169
120	2.075	657.8	1.2429	2.005	657.0	1.2383	1.939	656.1	1.2336	1.877	655.2	1.2291
130	2 125	664.4	1.2542	2.054	663.6	1.2497	1.988	662.8	1.2452	1.924	662.1	1.2408
140	2 175	670 9	1.2652	2.103	670.1	1.2607	2.035	669.4	1.2563	1.971	668.7	1.2520
150	2.224	677 2	1.2757	2.150	676 5	1.2713	2.081	675.9	1.2669	2.016	675.2	1.2628
160	2.272	683.5	1.2859	2.197	682 9	1.2816	2.127	682.3	1.2773	2.061	681.6	1.2732
170	2.319	689.7	1.2958	2.243	689 1	1.2915	2.172	688.5	1.2873	2.105	687.9	1.2833
180	2.365	695.8	1 3054	2.289	695.2	1.3012	2.216	694.7	1.2971	2.148	694.1	1.2931
190	2 411	701 9	1.3148	2 334	701.3	1.3107	2.260	700.8	1.3066	2.191	700.3	1.3026
200	2 457	707 9	1 3240	2 378	707.4	1.3199	2.303	706.9	1.3159	2.233	706.4	1.3120
210	2 502	713.9	1 3331	2 422	713.5	1.3290	2.346	713.0	1.3249	2.275	712.5	1.3211
220	2.547	719.9	1.3419	2 465	719 5	1.3378	2.389	719.0	1.3338	2.317	718.5	1.3300
230	2.591	725 8	1.3506	2 508	725.4	1.3466	2.431	724.9	1.3426	2.358	724.5	1.3388
240	2.635	731.7	1 3591	2.551	731.3	1.3551	2.473	730.9	1.3512	2.398	730.5	1.3474
250	2 679	737 6	1 3675	2 594	737.2	1.3635	2.514	736.8	1.3596	2.439	736.4	1.3558
260	2.723	743.5	1.3757	2.636	743.2	1.3718	2.555	742.8	1.3679	2.479	742.4	1.3642
270	2.766	749.4	1.3838	2.678	749.1	1.3799	2.596	748.7	1.3761	2.519	748.3	1.3724
280	2.809	755.3	1.3919	2.720	755.0	1.3880	2.637	754.6	1.3841	2.558	754.3	1.3804
290	2.852	761.2	1.3998	2.762	760.9	1.3959	2.678	760.5	1.3921	2.598	760.2	1.3884
300	2.895	767.1	1.4076	2.804	766.8	1.4037	2.718	766.4	1.3999	2.637	766.1	1.3963
310	2.937	773.0	1.4153	2.845	772.7	1.4114	2.758	772.3	1.4076	2.677	772.0	1.4040
320	2.980	778.9	1.4229	2.886	778.6	1.4191	2.798	778.3	1.4153	2.716	778.0	1.4117
330	3.022	784.8	1.4304	2.927	784.5	1.4266	2.838	784.2	1.4228	2.754	783.9	1.4192
340	3.064	790.7	1.4379	2.968	790.4	1.4341	2.878	790.1	1.4303	2.793	789.9	1.4267
350	3 106	796.6	1.4452	3.009	796.4	1.4414	2.918	796.2	1.4377	2.832	795.9	1.4341
360	3.148	802.5	1.4525	3.050	802.3	1.4487	2.957	802.0	1.4450	2.870	801.8	1.4464
370	3.189	808.5	1.4597	3.090	808.3	1.4559	2.997	808.0	1.4522	2.909	807.8	1.4486
380	3.231	814 5	1.4669	3.131	814.2	1.4631	3.036	814.0	1.4594	2.947	813.8	1.4558
390	3.273	820.4	1.4740	3.171	820.2	1.4702	3.075	820.0	1.4665	2.985	819.7	1.4629
400	3.314	826.4	1.4810	3.211	826.2	1.4772	3.114	826.0	1.4735	3.023	825.7	1.4700

TABLE 2A-2. PROPERTIES OF SUPERHEATED AMMONIA (*Continued*)

(*Arranged by American Society of Refrigerating Engineers from the Bureau of Standards Tables. From A.S.R.E. Data Book*)

Temp. °F.	Abs. Pressure 180 lb./in.² Gage Pressure 165.3 lb./in.² (Sat'n. Temp. 89.78° F.)			Abs. Pressure 185 lb./in.² Gage Pressure 170.3 lb./in.² (Sat'n. Temp. 91.47° F.)			Abs. Pressure 190 lb./in.² Gage Pressure 175.3 lb./in.² (Sat'n. Temp. 93.13° F.)			Abs. Pressure 195 lb./in.² Gage Pressure 180.3 lb./in.² (Sat'n. Temp. 94.75° F.)		
t	*V*	*H*	*S*	*V*	*H*	*S*	*V*	*H*	*S*	*V*	*H*	*S*
(at sat'n)	(*1.667*)	(*632.0*)	(*1.1850*)	(*1.623*)	(*632.2*)	(*1.1825*)	(*1.581*)	(*632.4*)	(*1.1802*)	(*1.540*)	(*632.6*)	(*1.1778*)
90	1.668	632.2	1.1853	......	......	......	......	......	......	......	......	......
100	1.720	639.9	1.1992	1.666	638.9	1.1945	1.615	637.8	1.1899	1.566	636.7	1.1854
110	1.770	647.3	1.2123	1.715	646.3	1.2078	1.663	645.4	1.2034	1.614	644.4	1.1990
120	1.818	654.4	1.2247	1.762	653.5	1.2203	1.710	652.6	1.2160	1.660	651.7	1.2118
130	1.865	661.3	1.2364	1.803	660.5	1.2322	1.755	659.7	1.2281	1.704	658.9	1.2240
140	1.910	668.0	1.2477	1.853	667.3	1.2436	1.799	666.5	1.2396	1.747	665.8	1.2356
150	1.955	674.6	1.2588	1.897	673 9	1.2546	1.842	673.2	1.2506	1.789	672.5	1.2467
160	1.999	681.0	1.2691	1.940	680.3	1.2651	1.884	679.7	1.2612	1.831	679.0	1.2574
170	2.042	687.3	1.2792	1.982	686.7	1.2753	1.925	686.1	1.2715	1.871	685.5	1.2678
180	2.084	693.6	1.2891	2.024	693.0	1.2853	1.966	692.5	1.2815	1.911	691.9	1.2778
190	2.126	699.8	1.2987	2.065	699.2	1.2950	2.005	698.7	1.2912	1.950	698.2	1.2876
200	2.167	705.9	1.3081	2.105	705.4	1.3044	2.045	704.9	1.3007	1.989	704.4	1.2971
210	2.203	712.0	1.3172	2.145	711.5	1.3135	2.084	711.1	1.3099	2.027	710.6	1.3064
220	2.248	718.1	1.3262	2.185	717.6	1.3225	2.123	717.2	1.3189	2.064	716.7	1.3154
230	2.288	724.1	1.3350	2.224	723.6	1.3314	2.161	723.2	1.3278	2.102	722.8	1.3243
240	2.328	730.1	1.3436	2.262	729.7	1.3400	2.199	729.3	1.3365	2.139	728.8	1.3330
250	2.367	736.1	1.3521	2.300	735.7	1.3485	2.236	735.3	1.3450	2.176	734.9	1.3416
260	2.407	742.0	1.3605	2.338	741.6	1.3569	2.274	741.3	1.3534	2.212	740.9	1.3500
270	2.446	748.0	1.3687	2.376	747.6	1.3652	2.311	747.3	1.3617	2.249	746.9	1.3583
280	2.484	753.9	1.3768	2.414	753.6	1.3733	2.348	753.2	1.3698	2.285	752.8	1.3664
290	2.523	759.9	1.3847	2.451	759.5	1.3812	2.384	759.2	1.3778	2.320	758.8	1.3745
300	2.561	765.8	1.3926	2.489	765.5	1.3891	2.421	765.2	1.3857	2.356	764.8	1.3824
310	2.599	771.7	1.4004	2.526	771.4	1.3969	2.457	771.1	1.3935	2.391	770.8	1.3902
320	2.637	777.7	1.4081	2.563	777.4	1.4046	2.493	777.1	1.4012	2.427	776.8	1.3979
330	2.675	783.6	1.4156	2.600	783.4	1.4122	2.529	783.1	1.4088	2.462	782.8	1.4055
340	2.713	789.6	1.4231	2.637	789.3	1.4197	2.565	789.0	1.4163	2.497	788.8	1.4131
350	2.750	795.6	1.4305	2.674	795.3	1.4271	2.601	795.1	1.4238	2.532	794.8	1.4205
360	2.788	801.5	1.4379	2.710	801.3	1.4345	2.637	801.0	1.4311	2.567	800.8	1.4279
370	2.825	807.5	1.4451	2.746	807.3	1.4417	2.672	807.0	1.4384	2.601	806.8	1.4352
380	2.863	813.5	1.4523	2.783	813.3	1.4489	2.707	813.0	1.4456	2.636	812.8	1.4424
390	2.900	819.5	1.4594	2.819	819.3	1.4560	2.743	819.0	1.4527	2.670	818.8	1.4495
400	2.937	825.5	1.4665	2.855	825.3	1.4631	2.778	825.1	1.4598	2.705	824.8	1.4566

Temp. °F.	Abs. Pressure 200 lb./in.² Gage Pressure 185.3 lb./in.² (Sat'n. Temp. 96.34° F.)			Abs. Pressure 205 lb./in.² Gage Pressure 190.3 lb./in.² (Sat'n. Temp. 97.90° F.)			Abs. Pressure 210 lb./in.² Gage Pressure 195.3 lb./in.² (Sat'n. Temp. 99.43° F.)			Abs. Pressure 220 lb./in.² Gage Pressure 205.3 lb./in.² (Sat'n. Temp. 102.42° F.)		
(at sat'n)	*(1.502)*	*(632.7)*	*(1.1756)*	*(1.466)*	*(632.8)*	*(1.1734)*	*(1.431)*	*(633.0)*	*(1.1713)*	*(1.367)*	*(633.2)*	*(1.1671)*
100	1.520	635.6	1.1809	1.476	634.5	1.1765	....	....	....	....	....	....
110	1.567	643.4	1.1947	1.522	642.4	1.1905	1.480	641.5	1.1863	1.400	639.4	1.1781
120	1.612	650.9	1.2077	1.566	650.0	1.2036	1.524	649.1	1.1996	1.443	647.3	1.1917
130	1.656	658.1	1.2200	1.609	657.2	1.2160	1.566	656.4	1.2121	1.485	654.8	1.2045
140	1.698	665.0	1.2317	1.651	664.2	1.2278	1.608	663.5	1.2240	1.525	662.0	1.2167
150	1.740	671.8	1.2429	1.693	671.1	1.2391	1.648	670.4	1.2354	1.564	669.0	1.2281
160	1.780	678.4	1.2537	1.733	677.7	1.2500	1.687	677.1	1.2464	1.601	675.8	1.2394
170	1.820	684.9	1.2641	1.772	684.3	1.2605	1.725	683.7	1.2569	1.638	682.5	1.2501
180	1.859	691.3	1.2742	1.810	690.7	1.2707	1.762	690.2	1.2672	1.675	689.1	1.2604
190	1.897	697.7	1.2840	1.847	697.1	1.2805	1.799	696.6	1.2771	1.710	695.5	1.2704
200	1.935	703.9	1.2935	1.884	703.4	1.2901	1.836	702.9	1.2867	1.745	701.9	1.2801
210	1.972	710.1	1.3029	1.921	709.6	1.2995	1.872	709.2	1.2961	1.780	708.2	1.2893
220	2.009	716.3	1.3120	1.957	715.8	1.3086	1.907	715.3	1.3053	1.814	714.4	1.2989
230	2.046	722.4	1.3209	1.993	721.9	1.3176	1.942	721.5	1.3143	1.848	720.6	1.3079
240	2.082	728.4	1.3296	2.028	728.0	1.3264	1.977	727.6	1.3231	1.881	726.8	1.3168
250	2.118	734.5	1.3382	2.064	734.1	1.3349	2.011	733.7	1.3317	1.914	732.9	1.3255
260	2.154	740.5	1.3467	2.099	740.1	1.3434	2.046	739.8	1.3402	1.947	739.0	1.3340
270	2.189	746.5	1.3550	2.133	746.1	1.3518	2.080	745.8	1.3486	1.980	745.1	1.3424
280	2.225	752.5	1.3631	2.168	752.1	1.3599	2.113	751.8	1.3568	2.012	751.1	1.3507
290	2.260	758.5	1.3712	2.202	758.2	1.3680	2.147	757.9	1.3649	2.044	757.2	1.3588
300	2.295	764.5	1.3791	2.236	764.2	1.3759	2.180	763.9	1.3728	2.076	763.2	1.3668
310	2.329	770.5	1.3869	2.270	770.2	1.3837	2.213	769.9	1.3806	2.108	769.3	1.3747
320	2.364	776.5	1.3947	2.304	776.2	1.3915	2.246	775.9	1.3884	2.140	775.3	1.3825
330	2.398	782.5	1.4023	2.337	782.2	1.3992	2.279	781.9	1.3961	2.171	781.3	1.3902
340	2.432	788.5	1.4099	2.371	788.2	1.4068	2.312	787.9	1.4037	2.203	787.4	1.3978
350	2.466	794.5	1.4173	2.404	794.2	1.4142	2.345	794.0	1.4112	2.234	793.5	1.4053
360	2.500	800.5	1.4241	2.437	800.3	1.4216	2.377	800.0	1.4186	2.265	799.5	1.4127
370	2.534	806.5	1.4320	2.470	806.3	1.4289	2.409	806.0	1.4259	2.296	805.5	1.4200
380	2.568	812.5	1.4392	2.503	812.3	1.4361	2.442	812.0	1.4331	2.327	811.6	1.4273
390	2.601	818.6	1.4464	2.536	818.4	1.4433	2.474	818.1	1.4403	2.358	817.6	1.4345
400	2.635	824.6	1.4534	2.569	824.4	1.4504	2.506	8.242	1.4474	2.388	823.7	1.4416

TABLE 2A–2. PROPERTIES OF SUPERHEATED AMMONIA (*Continued*)

(*Arranged by American Society of Refrigerating Engineers from the Bureau of Standards Tables. From A.S.R.E. Data Book*)

Temp. °F.	Abs. Pressure 230 lb./in.² Gage Pressure 215.3 lb./in.² (Sat'n. Temp. 105.30° F.)			Abs. Pressure 240 lb./in.² Gage Pressure 225.3 lb./in.² (Sat'n. Temp. 108.09° F.)			Abs. Pressure 250 lb./in.² Gage Pressure 235.3 lb./in.² (Sat'n. Temp. 110.80° F.)			Abs. Pressure 260 lb /in.² Gage Pressure 245.3 lb./in.² (Sat'n. Temp. 113.42° F.)		
°F	V	H	S	V	H	S	V	H	S	V	H	S
(at sat'n)	(1.307)	(633.4)	(1.1631)	(1.253)	(633.6)	(1.1592)	(1.202)	(633.8)	(1.1555)	(1.155)	(633.9)	(1.1518)
110	1.328	637.4	1.1700	1.261	635.3	1.1621	......	......	......	......	......	......
120	1.370	645.4	1.1840	1.302	643.5	1.1764	1.240	641.5	1.1690	1.182	639.5	1.1617
130	1.410	653.1	1.1971	1.342	651.3	1.1898	1.278	649.6	1.1827	1.220	647.8	1.1757
140	1.449	660.4	1.2095	1.380	658.8	1.2025	1.316	657.2	1.1956	1.257	655.6	1.1889
150	1.487	667.6	1.2213	1.416	666.1	1.2145	1.352	664.6	1.2078	1.292	663.1	1.2014
160	1.524	674.5	1.2325	1.452	673.1	1.2259	1.386	671.8	1.2195	1.326	670.4	1.2132
170	1.559	681.3	1.2434	1.487	680.0	1.2369	1.420	678.7	1.2306	1.359	677.5	1.2245
180	1.594	687.9	1.2538	1.521	686.7	1.2475	1.453	685.5	1.2414	1.391	684.4	1.2354
190	1.629	694.4	1.2640	1.554	693.3	1.2577	1.486	692.2	1.2517	1.422	691.1	1.2458
200	1.663	700.9	1.2738	1.587	699.8	1.2677	1.518	698.8	1.2617	1.453	697.7	1.2560
210	1.696	707.2	1.2834	1.619	706.2	1.2773	1.549	705.3	1.2715	1.484	704.3	1.2658
220	1.729	713.5	1.2927	1.651	712.6	1.2867	1.580	711.7	1.2810	1.514	710.7	1.2754
230	1.762	719.8	1.3018	1.683	718.9	1.2959	1.610	718.0	1.2902	1.543	717.1	1.2847
240	1.794	726.0	1.3107	1.714	725.1	1.3049	1.640	724.3	1.2993	1.572	723.4	1.2938
250	1.826	732.1	1.3195	1.745	731.3	1.3137	1.670	730.5	1.3081	1.601	729.7	1.3027
260	1.857	738.3	1.3281	1.775	737.5	1.3224	1.699	736.7	1.3168	1.630	736.0	1.3115
270	1.889	744.4	1.3365	1.805	743.6	1.3308	1.729	742.9	1.3253	1.658	742.2	1.3200
280	1.920	750.5	1.3448	1.835	749.8	1.3392	1.758	749.1	1.3337	1.686	748.4	1.3285
290	1.951	756.5	1.3530	1.865	755.9	1.3474	1.786	755.2	1.3420	1.714	754.5	1.3367
300	1.982	762.6	1.3610	1.895	762.0	1.3554	1.815	761.3	1.3501	1.741	760.7	1.3449
310	2.012	768.7	1.3689	1.924	768.0	1.3633	1.843	767.4	1.3581	1.769	766.8	1.3529
320	2.043	774.7	1.3767	1.954	774.1	1.3712	1.872	773.5	1.3659	1.796	772.9	1.3608
330	2.073	780.8	1.3844	1.983	780.2	1.3790	1.900	779.6	1.3737	1.823	779.0	1.3686
340	2.103	786.8	1.3921	2.012	786.3	1.3866	1.928	785.7	1.3814	1.850	785.2	1.3763
350	2.133	793.0	1.3996	2.040	792.4	1.3942	1.955	791.9	1.3889	1.877	791.4	1.3839
360	2.163	798.9	1.4070	2.069	798.4	1.4016	1.983	797.9	1.3964	1.904	797.4	1.3914
370	2.193	805.0	1.4144	2.098	804.5	1.4090	2.011	804.0	1.4038	1.930	803.5	1.3988
380	2.222	811.1	1.4217	2.126	810.6	1.4163	2.038	810.1	1.4111	1.957	809.6	1.4062
390	2.252	817.2	1.4289	2.155	816.7	1.4235	2.065	816.2	1.4183	1.983	815.8	1.4134
400	2.281	823.3	1.4360	2.183	822.8	1.4307	2.093	822.3	1.4255	2.009	821.9	1.4206

Temp. °F.	Abs. Pressure 270 lb./in.² Gage Pressure 255.3 lb./in.² (Sat'n. Temp. 115.97° F.)			Abs. Pressure 280 lb./in.² Gage Pressure 265.3 lb./in.² (Sat'n. Temp. 118.45° F.)			Abs. Pressure 290 lb./in.² Gage Pressure 275.3 lb./in.² (Sat'n. Temp. 120.86° F.)			Abs. Pressure 300 lb./in.² Gage Pressure 285.3 lb./in.² (Sat'n. Temp. 123.21° F.)		
(at sat'n)	*(1.112)*	*(633.9)*	*(1.1483)*	*(1.072)*	*(634.0)*	*(1.1449)*	*(1.034)*	*(634.0)*	*(1.1415)*	*(0.999)*	*(634.0)*	*(1.1383)*
120	1.128	637.5	1.1544	1 078	635 4	1.1473	......	......	......	......	......	......
130	1.166	645.9	1.1689	1.115	644.0	1 1621	1.068	642.1	1 1554	1.023	640.1	1.1487
140	1.202	653.9	1.1823	1.151	652.2	1.1759	1.103	650.5	1.1695	1.058	648.7	1.1632
150	1.236	661.6	1.1950	1.184	660.1	1.1888	1.136	658.5	1 1827	1.091	656.9	1.1767
160	1.269	669.0	1.2071	1.217	667.6	1.2011	1.168	666.1	1.1952	1.123	664.7	1.1894
170	1.302	676 2	1.2185	1.249	674.9	1.2127	1.199	673.5	1.2070	1.153	672.2	1.2014
180	1.333	683.2	1.2296	1.279	681.9	1.2239	1.229	680.7	1.2183	1.183	679.5	1.2129
190	1.364	690.0	1.2401	1.309	688.9	1.2346	1.259	687.7	1.2292	1.211	686.5	1.2239
200	1.394	696.7	1.2504	1.339	695.6	1.2449	1.287	694.6	1.2396	1.239	693.5	1.2344
210	1.423	703.3	1.2603	1.367	702.3	1.2550	1.315	701.3	1.2497	1.267	700.3	1.2447
220	1.452	709.8	1.2700	1.396	708.8	1.2647	1.343	707.9	1.2596	1.294	706.9	1.2546
230	1.481	716.2	1.2794	1.424	715.3	1.2742	1.370	714.4	1.2691	1.320	713.5	1.2642
250	1.509	772.6	1.2885	1.451	721.8	1.2834	1.397	720.9	1.2784	1.346	720.0	1.2736
250	1 537	728.9	1.2975	1.478	728.1	1.2924	1.423	727.3	1.2875	1.372	726.5	1 2827
260	1.565	735.2	1.3063	1 505	734.4	1.3013	1.449	733.7	1 2964	1.397	732.9	1.2917
270	1.592	741.4	1.3149	1.532	740.7	1.3099	1.475	740.0	1.3051	1.422	739.2	1.3004
280	1.620	747.7	1.3234	1.558	747.0	1 3184	1.501	746.3	1.3137	1.447	745.5	1.3090
290	1.646	753.9	1.3317	1.584	753.2	1.3268	1.526	752.5	1.3221	1.472	751.8	1.3175
300	1.673	760.0	1.3399	1.610	759 4	1.3350	1.551	758.7	1.3303	1.496	758.1	1.3257
310	1.700	766.2	1.3480	1.635	765.6	1.3431	1.576	764.9	1.3384	1.520	764.3	1 3338
320	1 726	772 3	1.3559	1.661	771.7	1.3511	1.601	771.1	1.3464	1.544	770.5	1.3419
330	1.752	778.5	1.3647	1.686	777.9	1.3590	1.625	777.3	1 3543	1.568	776.7	1.3498
340	1.778	784.6	1.3714	1.712	784.0	1.3667	1.650	783.5	1 3621	1.592	782.9	1.3576
350	1.804	790 8	1.3790	1.737	790.3	1.3743	1.674	789 7	1 3697	1 616	789 1	1.3653
360	1.830	796.9	1 3866	1.762	796 3	1.3819	1.698	795.8	1.3773	1.639	795.3	1.3729
370	1 856	803.0	1.3940	1.787	802.5	1.3893	1.722	802.0	1.3848	1.662	801.5	1.3804
380	1.881	809.1	1.4014	1.811	808.7	1.3967	1.747	808.2	1.3922	1.686	807.7	1.3878
390	1.907	815.3	1.4086	1.836	814.8	1.4040	1.770	814.3	1.3995	1.709	813.9	1.3951
400	1.932	821 4	1.4158	1.861	821.0	1.4112	1.794	820.5	1.4067	1.732	820.1	1.4024

TABLE 2A-3. PROPERTIES OF LIQUID AMMONIA

(Arranged from Tables of U. S. Bureau of Standards)

Temperature °F. t	Saturation Pressure (abs.) lbs./in.^{2} p	Volume ft.^{3}/lb. v	Density lbs./ft.^{3} $\frac{1}{v}$	Specific Heat Btu./lb. °F. c	Heat Content Btu./lb. h	Latent Heat Btu./lb. L
−50	7.67	0.02299	43.49	1.058	−10.61	604.3
−45	8.95	.02310	43.28	1.060	− 5.31	600.9
−40	10.41	.02322	43.08	1.062	0.00	597.6
−35	12.05	.02333	42.86	1.064	+ 5.32	594.2
−30	13.90	0.2345	42.65	1.066	10.66	590.7
−25	15.98	0.02357	42.44	1.068	16.00	587.2
−20	18.30	.02369	42.22	1.070	21.36	583.6
−15	20.88	.02381	42.00	1.073	26.73	580.0
−10	23.74	.02393	41.78	1.075	32.11	576.4
− 5	26.92	.02406	41.56	1.078	37.51	572.6
0	30.42	0.02419	41.34	1.080	42.92	568.9
5	34.27	.02432	41.11	1.083	48.35	565.0
10	38.51	.02446	40.89	1.085	53.79	561.1
15	43.14	.02460	40.66	1.088	59.24	557.1
20	48.21	.02474	40.43	1.091	64.71	553.1
25	53.73	0.02488	40.20	1.094	70.20	548.9
30	59.74	.02503	39.96	1.097	75.71	544.8
35	66.26	.02518	39.72	1.100	81.23	540.5
40	73.32	.02533	39.49	1.104	86.77	536.2
45	80.96	.02548	39.24	1.108	92.34	531.8
50	89.19	0.02564	39.00	1.112	97.93	527.3
55	98.06	.02581	38.75	1.116	103.54	522.8
60	107.6	.02597	38.50	1.120	109.18	518.1
65	117.8	.02614	38.25	1.125	114.85	513.4
70	128.8	.02632	38.00	1.129	120.54	508.6
75	140.5	0.02650	37.74	1.133	126.25	503.7
80	153.0	.02668	37.48	1.138	131.99	498.7
85	166.4	.02687	37.21	1.142	137.75	493.6
90	180.6	.02707	36.95	1.147	143.54	488.5
95	195.8	.02727	36.67	1.151	149.36	483.2
100	211.9	0.02747	36.40	1.156	155.21	477.8
105	228.9	.02769	36.12	1.162	161.09	472.3
110	247.0	.02790	35.84	1.168	167.01	466.7
115	266.2	.02813	35.55	1.176	172.97	460.9
120	286.4	.02836	35.26	1.183	178.98	455.0

CARBON DIOXIDE

TABLE 2A–4. PROPERTIES OF SATURATED CARBON DIOXIDE

(Arranged by American Society of Refrigerating Engineers)

Temp.	Pressure			Volume		Density		Enthalpy Above 32° F			Entropy From 32° F.			
°F. t	Abs. lb./in.² p	Gage Atmos. at./in.² a-gp	Gage lb./in.² gp	Liquid ft.³/lb. v	Vapor ft³/lb V	Liquid lb/ft.³ $1/v$	Vapor lb./ft.³ $1/V$	Liquid Btu./lb. h	Latent Btu./lb L	Vapor Btu/lb. H	Liquid Btu./lb. s	Evap. Btu./lb L/T	Vapor Btu./lb. S	Temp. °F. t
−22	212.9	13.48	198.2	0.0155	0.4319	64.52	2.315	−24.78	126.7	102.0	−0.0533	0.2898	0.2365	−22
−21	216.7	13.74	202.0	.0155	.4242	64.43	2.358	−24.37	126.4	102.0	− .0524	.2883	.2359	−21
−20	220.6	14.00	205.9	0.0155	0.4166	64.34	2.401	−23.96	126.0	102.0	−0.0514	0.2867	0.2353	−20
−19	224.4	14.27	209.7	.0156	.4091	64.25	2.444	−23.54	125.6	102.1	− .0505	.2852	.2348	−19
−18	228.4	14.53	213.7	.0156	.4018	64.15	2.489	−23.13	125.2	102.1	− .0495	.2837	.2342	−18
−17	232.3	14.80	217.6	.0156	.3946	64.05	2.534	−22.71	124.9	102.1	− .0486	.2822	.2336	−17
−16	236.4	15.08	221.7	.0156	.3876	63.94	2.580	−22.30	124.5	102.2	− .0476	.2807	.2331	−16
−15	240.5	15.36	225.8	0.0157	0.3807	63.84	2.627	−21.88	124.1	102.2	−0.0467	0.2792	0.2325	−15
−14	244.6	15.64	229.9	.0157	.3739	63.73	2.674	−21.46	123.7	102.2	− .0458	.2777	.2319	−14
−13	248.8	15.92	234.1	.0157	.3673	63.61	2.723	−21.03	123.3	102.2	− .0448	.2761	.2313	−13
−12	253.0	16.21	238.3	.0157	.3608	63.49	2.772	−20.61	122.9	102.3	− .0439	.2746	.2307	−12
−11	258.3	16.50	242.6	.0158	.3544	63.37	2.822	−20.18	122.5	102.3	− .0429	.2731	.2302	−11
−10	261.7	16.80	247.0	0.0158	0.3482	63.25	2.872	−19.76	122.0	102.3	−0.0420	0.2716	0.2296	−10
− 9	266.1	17.10	251.4	.0158	.3420	63.13	2.924	−19.33	121.6	102.3	− .0410	.2700	.2290	− 9
− 8	270.6	17.41	255.9	.0159	.3360	63.01	2.976	−18.90	121.2	102.3	− .0401	.2685	.2284	− 8
− 7	275.1	17.72	260.4	.0159	.3301	62.88	3.029	−18.47	120.8	102.3	− .0391	.2669	.2278	− 7
− 6	279.7	18.03	265.0	.0159	.3243	62.76	3.083	−18.04	120.3	102.3	− .0382	.2654	.2273	− 6
− 5	284.4	18.35	269.7	0.0160	0.3186	62.63	3.138	−17.61	119.9	102.3	−0.0372	0.2639	0.2267	− 5
− 4	289.1	18.67	274.4	.0160	.3131	62.50	3.194	−17.17	119.5	102.3	− .0362	.2623	.2261	− 4
− 3	293.9	18.99	279.2	.0160	.3076	62.37	3.251	−16.73	119.0	102.3	− .0353	.2608	.2255	− 3
− 2	298.7	19.32	284.0	.0161	.3022	62.23	3.309	−16.29	118.6	102.3	− .0343	.2592	.2249	− 2
− 1	303.6	19.66	288.9	.0161	.2969	62.09	3.368	−15.85	118.1	102.3	− .0334	.2577	.2243	− 1

0	308.6	20.00	293.9	0.0161	0.2918	61.95	3.427	−15.41	117.7	102.2	−0.0324	0.2561	0.2237	0
1	313.7	20.34	299.0	.0162	.2867	61.80	3.483	−14.96	117.2	102.2	− .0314	.2545	.2231	1
2	318.7	20.68	304.0	.0162	.2817	61.65	3.550	−14.51	116.7	102.2	− .0304	.2530	.2225	2
3	323.9	21.03	309.2	.0163	.2768	61.51	3.612	−14.07	116.2	102.2	− .0295	.2514	.2219	3
4	329.1	21.39	314.4	.0163	.2720	61.36	3.676	−13.61	115.8	102.1	− .0285	.2498	.2213	4
‡5	**334.4**	**21.75**	**319.7**	**0.0163**	**0.2673**	**61.22**	**3.741**	**−13.16**	**115.3**	**102.1**	**−0.0275**	**0.2482**	**0.2207**	**5‡**
6	339.8	22.11	325.1	.0164	.2627	61.07	3.807	−12.71	114.8	102.1	− .0266	.2466	.2201	6
7	345.2	22.48	330.5	.0164	.2581	60.92	3.874	−12.25	114.3	102.0	− .0256	.2451	.2195	7
8	350.7	22.85	336.0	.0165	.2537	60.77	3.942	−11.79	113.8	102.0	− .0246	.2435	.2189	8
9	356.2	23.23	341.5	.0165	.2493	60.63	4.011	−11.33	113.3	102.0	− .0236	.2419	.2183	9
10	361.8	23.61	347.1	0.0165	0.2450	60.48	4.082	−10.87	112.8	101.9	−0.0226	0.2402	0.2176	10
11	367.5	24.00	352.8	.0166	.2408	60.33	4.154	−10.40	112.3	101.9	− .0216	.2386	.2170	11
12	373.3	24.39	358.6	.0166	.2366	60.18	4.227	− 9.934	111.7	101.8	− .0206	.2370	.2164	12
13	379.1	24.79	364.4	.0167	.2325	60.03	4.301	− 9.464	111.2	101.7	− .0196	.2354	.2158	13
14	385.0	25.19	370.3	.0167	.2285	59.88	4.377	− 8.992	110.7	101.7	− .0186	.2338	.2151	14
15	391.0	25.60	376.3	0.0167	0.2245	59.73	4.454	− 8.515	110.1	101.6	−0.0176	0.2321	0.2145	15
16	397.1	26.01	382.4	.0168	.2207	59.58	4.532	− 8.038	109.6	101.5	− .0166	.2305	.2139	16
17	403.2	26.43	388.5	.0168	.2168	59.42	4.611	− 7.557	109.0	101.5	− .0156	.2288	.2132	17
18	409.4	26.85	394.7	.0169	.2131	59.27	4.692	− 7.076	108.5	101.4	− .0146	.2272	.2126	18
19	415.7	27.28	401.0	.0169	.2094	59.11	4.775	− 6.591	107.9	101.3	− .0136	.2255	.2119	19
20	422.0	27.71	407.3	0.0170	0.2058	58.95	4.859	− 6.102	107.3	101.2	−0.0126	0.2239	0.2113	20
21	428.4	28.14	413.7	.0170	.2023	58.79	4.944	− 5.610	106.7	101.1	− .0115	.2222	.2106	21
22	434.9	28.58	420.2	.0171	.1987	58.64	5.031	− 5.117	106.1	101.0	− .0105	.2205	.2100	22
23	441.4	29.03	426.7	.0171	.1953	58.47	5.120	− 4.621	105.6	100.9	− .0095	.2188	.2093	23
24	448.1	29.48	433.4	.0172	.1919	58.31	5.211	− 4.121	104.9	100.8	− .0085	.2171	.2087	24
25	454.8	29.94	440.1	0.0172	0.1886	58.14	5.303	− 3.618	104.3	100.7	−0.0074	0.2154	0.2080	25
26	461.6	30.40	446.9	.0172	.1853	57.98	5.396	− 3.111	103.7	100.6	− .0064	.2137	.2073	26
27	468.5	30.87	453.8	.0173	.1821	57.81	5.492	− 2.601	103.1	100.5	− .0053	.2120	.2066	27
28	475.4	31.34	460.7	.0174	.1789	57.64	5.589	− 2.087	102.5	100.4	− .0043	.2102	.2059	28
29	482.5	31.82	467.8	.0174	.1758	57.47	5.688	− 1.570	101.8	100.2	− .0032	.2085	.2053	29

‡ Standard ton temperatures.

TABLE 2A–4. PROPERTIES OF SATURATED CARBON DIOXIDE (*Continued*)

(*Arranged by American Society of Refrigerating Engineers*)

Temp.	Pressure			Volume		Density		Enthalpy Above 32° F			Entropy From 32° F.			Temp.
°F. *t*	Abs. lb./in.^{2} *p*	Gage Atmos. at./in.^{2} *a-g p*	Gage lb./in.^{2} *g p*	Liquid ft.^{3}/lb. *v*	Vapor ft.^{3}/lb. *V*	Liquid lb./ft.^{3} *1/v*	Vapor lb./ft.^{3} *1/V*	Liquid Btu./lb. *h*	Latent Btu./lb *L*	Vapor Btu./lb *H*	Liquid Btu./lb. *s*	Evap. Btu./lb *L/T*	Vapor Btu./lb. *S*	°F. *t*
30	489.6	32.31	474.9	0.0175	0.1728	57.30	5.789	− 1.049	101.2	100.1	−0.0021	0.2067	0.2046	30
31	496.8	32.79	482.1	.0175	.1697	57.12	5.892	− 0.525	100.5	99.98	− .0011	.2049	.2039	31
32	504.1	33.29	489.4	.0176	.1668	56.95	5.996	0.000	99.83	99.83	− .0000	.2032	.2032	32
33	511.4	33.79	496.7	.0176	.1639	56.77	6.103	+ 0.531	99.16	99.69	+ .0011	.2014	.2025	33
34	518.9	34.30	504.2	.0177	.1610	56.59	6.212	+ 1.066	98.47	99.54	+ .0022	.1996	.2017	34
35	526.4	34.81	511.7	0.0177	0.1581	56.41	6.323	1.604	97.77	99.38	0.0033	0.1978	0.2010	35
36	534.0	35.33	519.3	.0178	.1554	56.22	6.437	2.149	97.07	99.22	.0044	.1959	.2003	36
37	541.7	35.85	527.0	.0178	.1526	56.03	6.553	2.697	96.35	99.05	.0055	.1941	.1996	37
38	549.5	36.38	534.8	.0179	.1499	55.84	6.671	3.248	95.62	93.87	.0066	.1922	.1988	38
39	557.4	36.92	542.7	.0180	.1472	55.65	6.792	3.806	94.88	98.69	.0077	.1904	.1981	39
40	565.4	37.46	550.7	0.0180	0.1446	55.45	6.915	4.367	94.13	98.50	0.0088	0.1885	0.1973	40
41	573.4	38.01	558.7	.0181	.1420	55.25	7.040	4.932	93.37	98.31	.0099	.1866	.1965	41
42	581.6	38.56	566.9	.0182	.1395	55.04	7.169	5.503	92.60	98.10	.0111	.1847	.1958	42
43	589.8	39.12	575.1	.0182	.1370	54.84	7.300	6.080	91.82	97.90	.0122	.1828	.1950	43
44	598.1	39.69	583.4	.0183	.1345	54.62	7.434	6.664	91.02	97.68	.0134	.1808	.1942	44
45	606.5	40.26	591.8	0.0184	0.1321	54.41	7.571	7.251	90.21	97.46	0.0146	0.1788	0.1934	45
46	615.0	40.84	600.3	.0185	.1297	54.19	7.711	7.844	89.39	97.23	.0157	.1769	.1926	46
47	623.6	41.43	608.9	.0185	.1273	53.97	7.854	8.443	88.55	96.99	.0169	.1749	.1918	47
48	632.3	42.02	617.6	.0186	.1250	53.74	8.000	9.049	87.70	96.75	.0181	.1729	.1910	48
49	641.1	42.63	626.4	.0187	.1227	53.51	8.151	9.664	86.83	96.50	.0193	.1708	.1901	49
50	650.0	43.22	635.3	0.0188	0.1204	53.28	8.304	10.28	85.95	96.24	0.0205	0.1687	0.1893	50
51	659.0	43.83	644.3	.0189	.1182	53.04	8.461	10.91	85.06	95.97	.0218	.1666	.1884	51
52	668.1	44.45	653.4	.0189	.1160	52.80	8.622	11.55	84.14	95.69	.0230	.1645	.1875	52
53	677.3	45.07	662.6	.0190	.1138	52.55	8.787	12.19	83.21	95.40	.0243	.1624	.1867	53
54	686.5	45.70	671.8	.0191	.1116	52.30	8.957	12.84	82.26	95.10	.0255	.1602	.1858	54

55	695.9	46.84	681.2	0.0192	0.1095	52.05	9.132	13.49	81.29	94.78	0.0268	0.1580	[illegible]	55
56	705.4	46.98	690.7	.0193	.1074	51.79	9.313	14.16	80.30	94.46	.0281	.1558	.1839	56
57	714.9	47.63	700.2	.0194	.1053	51.53	9.497	14.84	79.30	94.13	.0294	.1536	.1830	57
58	724.6	48.29	709.9	.0195	.1032	51.26	9.686	15.53	78.27	93.79	.0307	.1513	.1820	58
59	734.3	48.96	719.6	.0196	.1012	50.99	9.880	16.22	77.22	93 44	.0321	.1490	.1811	59
60	744.2	49.63	729.5	0.0197	0.0992	50.71	10.08	16.93	76.14	93.07	0 0335	0.1466	0.1801	60
61	754.2	50.30	739.5	.0198	.0972	50.42	10.29	17.65	75.04	92.69	.0348	.1442	.1790	61
62	764.3	50.99	749.6	.0200	.0953	50.11	10.50	18.38	73.91	92.29	.0363	.1417	.1780	62
63	774.5	51.68	759.8	.0201	.0933	49.80	10.72	19.13	72.75	91.88	.0377	.1393	.1770	63
64	784.7	52.38	770.0	.0202	.0914	49.47	10.95	19.88	71.57	91.45	.0391	.1367	.1759	64
65	795.1	53.09	780.4	0.0203	0.0894	49.14	11.18	20.66	70 35	91.01	0 0406	0.1342	0.1748	65
66	805.6	53.80	790.9	.0205	.0875	48.80	11.42	21.45	69.10	90.55	.0421	.1315	.1736	66
67	816.2	54.53	801.5	.0206	.0856	48.44	11.67	22.25	67.81	90.07	.0436	.1288	.1725	67
68	827.0	55.26	812.3	.0208	.0838	48.08	11.94	23.08	66.49	89.56	.0452	.1261	.1713	68
69	837.8	55.99	823.1	.0210	.0319	47.69	12.21	23.92	65.12	89.04	.0468	.1233	.1701	69
70	848.7	56.74	834.0	0.0211	0.0800	47.29	12.49	24.78	63.71	88 49	0 0484	0 1204	0.1688	70
71	859.8	57.49	845.1	.0213	.0782	46.87	12.82	25.67	62 25	87.92	.0501	.1174	.1675	71
72	870.9	58.25	856.2	.0215	.0763	46.44	13.10	26.58	60.74	87.32	.0518	.1143	.1661	72
73	882.2	59.01	867.5	.0217	.0745	45.99	13.43	27.52	59.17	86.69	0536	.1111	.1647	73
74	893.6	59.79	878.9	.0220	.0726	45.53	13.77	28 49	57.54	86.03	.0554	1079	.1633	74
75	905.1	60.57	890.4	0.0222	0.0708	45.05	14.13	29.50	55.83	85.33	0 0573	0.1045	0.1618	75
76	916.7	61.36	902.0	.0224	.0689	44.56	14.51	30.54	54.05	84.59	.0592	.1010	[illegible]	76
77	928.4	62.16	913.7	.0227	.0671	44.06	14.90	31.62	52.17	83.80	.0613	.0973	.1585	77
78	940.3	62.96	925.6	.0230	.0652	43.55	15.34	32.76	50.20	82.96	.0634	.0934	.1568	78
79	952.2	63.78	937.5	.0232	.0633	43.04	15.81	33.95	48.11	82.06	.0656	[illegible]	.1550	79
80	964.3	64.60	949.6	0.0235	0.0613	42.50	16.32	35.21	45.88	81.09	0.0679	0.0851	0.1530	80
81	976.5	65.43	961.8	.0238	.0592	41.95	16.90	36.54	43.49	80.03	.0704	.0805	.1509	81
82	988.8	66.27	974.1	.0242	.0570	41.30	17.53	37.98	40.90	78.88	.0731	.0753	1486	82
83	1001.0	67.11	986.3	.0246	.0548	40.62	18.25	39.53	38.07	77.60	.0759	.0702	1461	83
84	1014.0	67.97	999.3	.0251	.0524	39.81	19.07	41.25	34.90	76.15	.0791	.0642	.1433	84
85	1027.0	68.83	1012.3	0.0258	0.0500	38.76	20.00	43.18	31.29	74.47	0.0826	0.0575	0.1401	85
86‡	1039.0	69.70	1024.3	.0267	.0474	37.41	21.09	45.45	27.00	72.46	.0868	.0495	.1363	86‡
87	1052.0	70.58	1037.3	.0283	.0446	35.34	22.42	48.32	21.52	69.84	.0921	.0394	.1314	87
88	1065.0	71.47	1050.3	.0305	.0401	32.79	24.95	52.78	12.84	65.62	.1002	.0235	.1237	88
88.43	1071.0	71.86	1056.3	.0346	.0346	28.90	28.90	59.23	0.00	59.23	.1120	.0000	.1120	88.43

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‡ Standard ton temperatures.

TABLE 2A-5. PROPERTIES OF SUPERHEATED CARBON DIOXIDE (– 75°–450° F.)

(*An abridged table from the work of R. L. Sweigert, Paul Weber, and R. L. Allen, Georgia School of Technology. Published by permission*)

Pressure *P*		Temperature, °F.											
		−75°	−50°	0°	50°	100°	150°	200°	250°	300°	350°	400°	450°
32.0	*V*	2.825	3.028	3.439	3.829	4.217	4.617	....					
	H	281.1	286.4	296.2	306.3	316.8	327.6	....					
	S	1.3196	1.3318	1.3540	1.3746	1.3938	1.4117	.....					
36.0	*V*	2.499	2.681	3.050	3.398	3.743	4.101						
	H	280.9	286.1	296.0	306.1	316.7	327.5						
	S	1.3140	1.3262	1.3485	1.3691	1.3883	1.4063						
40.0	*V*	2.239	2.404	2.738	3.053	3.363	3.688						
	H	280.6	285.9	295.8	305.9	316.5	327.4						
	S	1.3088	1.3211	1.3435	1.3642	1.3834	1.4014						
44.0	*V*	2.025	2.177	2.483	2.771	3.054	3.349						
	H	280.4	285.7	295.6	305.7	316.4	327.3						
	S	1.3040	1.3163	1.3388	1.3596	1.3789	1.3969						
48.0	*V*	1.847	1.987	2.270	2.535	2.795	3.068						
	H	280.1	285.5	295.4	305.5	316.2	327.2						
	S	1.2993	1.3118	1.3344	1.3553	1.3747	1.3928						
52.0	*V*	1.696	1.827	2.091	2.335	2.576	2.829						
	H	279.8	285.3	295.2	305.4	316.1	327.1						
	S	1.2944	1.3072	1.3301	1.3511	1.3706	1.3888						
56.0	*V*	1.568	1.690	1.936	2.164	2.388	2.625						
	H	279.6	285.1	295.0	305.2	316.0	327.0						
	S	1.2888	1.3024	1.3259	1.3472	1.3668	1.3851						
60.0	*V*	1.456	1.571	1.803	2.016	2.225	2.448						
	H	279.3	284.9	294.8	305.0	315.8	326.9						
	S	1.2801	1.2961	1.3213	1.3432	1.3631	1.3815						
70.0	*V*	....	1.329	1.536	1.720	1.901	2.094						
	H	....	284.4	294.3	304.5	315.4	326.7						
	S	......	1.2860	1.3120	1.3354	1.3557	1.3743						
80.0	*V*	....	1.154	1.335	1.498	1.657	1.828						
	H	....	283.8	293.8	304.1	315.1	326.4						
	S	.....	1.2778	1.3044	1.3284	1.3490	1.3679						
90.0	*V*	......	1.015	1.179	1.325	1.476	1.621						
	H	.....	283.3	293.3	303.6	314.7	326.2						
	S	.....	1.2709	1.2981	1.3224	1.3433	1.3623						
100	*V*	.....	0.905	1.055	1.187	1.316	1.456	.....					
	H	....	282.8	292.7	303.2	314.3	325.9						
	S	....	1.2649	1.2924	1.3171	1.3382	1.3573						
120	*V*	....	.....	0.8665	0.9799	1.088	1.208	....					
	H	......	....	291.7	302.2	313.6	325.4	....					
	S	....	....	1.2833	1.3086	1.3297	1.3488	..					

TABLE 2A-5. PROPERTIES OF SUPERHEATED CARBON DIOXIDE (− 75°–450° F.) (*Continued*)

(An abridged table from the work of R. L. Sweigert, Paul Weber, and R. L. Allen, Georgia School of Technology. Published by permission)

Pressure P		Temperature, °F.											
		−75°	−50°	0°	50°	100°	150°	200°	250°	300°	350°	400°	450°
140	V	...	...	0.7315	0.8317	0.9252	1.032				...	...	...
	H	...	...	290.7	301.3	312.8	324.9					...	...
	S	...	...	1.2747	1.3005	1.3220	1.3413					...	...
160	V	...	...	0.6305	0.7207	0.8033	0.8986					...	...
	H	...	...	289.7	300.4	312.1	324.4					...	...
	S	...	...	1.2666	1.2928	1.3154	1.3350				...	...	...
180	V	...	...	0.5519	0.6344	0.7110	0.7952					...	
	H	...	...	288.7	299.5	311.3	323.9					...	...
	S	...	...	1.2590	1.2865	1.3093	1.3291					...	...
200	V			0.4891	0.5652	0.6376	0.7125						...
	H	...	...	287.7	298.6	310.6	323.4						...
	S	...		1.2519	1.2805	1.3038	1.3239					...	...
220	V			0.4376	0.5087	0.5755	0.6450					...	...
	H		...	286.6	297.7	309.8	322.9						...
	S			1.2454	1.2748	1.2987	1.3191						...
240	V	...	...	0.3948	0.4614	0.5237	0.5886						...
	H			285.6	296.7	309.1	322.4					...	...
	S	...	...	1.2395	1.2694	1.2940	1.3145					...	...
260	V		...	0.3584	0.4215	0.4799	0.5406					...	...
	H		...	284.6	295.8	308.4	321.9					...	...
	S	...		1.2344	1.2643	1.2896	1.3105					...	...
280	V	...		0.3286	0.3865	0.4425	0.4994				...	...	...
	H	...		283.6	294.9	307.6	321.4					...	...
	S			1.2299	1.2596	1.2853	1.3064			...		...	...
300	V	...		...	0.3563	0.4100	0.4636	0.5065	0.5539	0.5985	0.6427	0.6868	0.7303
	H	...	...	...	294.0	306.9	320.9	333.9	345.1	357.1	369.3	381.6	394.3
	S	...	...	...	1.2562	1.2813	1.3029	1.3219	1.3395	1.3560	1.3715	1.3862	1.4002
320	V	...		...	0.3298	0.3815	0.4322	0.4729	0.5177	0.5601	0.6015	0.6422	0.6840
	H		...	...	293.1	306.1	320.4	333.5	344.7	356.8	369.0	381.4	394.2
	S	...		...	1.2518	1.2774	1.2993	1.3185	1.3364	1.3530	1.3685	1.3832	1.3972
340	V	...	...	...	0.3065	0.3564	0.4045	0.4434	0.4857	0.5261	0.5653	0.6037	0.6434
	H		...	...	292.2	305.4	319.9	333.2	344.4	356.5	368.8	381.2	394.0
	S	...	...	...	1.2477	1.2736	1.2958	1.3154	1.3334	1.3501	1.3657	1.3804	1.3944
360	V	...	...	...	0.2858	0.3341	0.3780	0.4171	0.4576	0.4958	0.5329	0.5693	0.6071
	H		...	...	291.2	304.6	319.4	332.8	344.0	356.3	368.6	381.0	393.7
	S	...	...	...	1.2436	1.2699	1.2925	1.3124	1.3306	1.3475	1.3631	1.3779	1.3919
380	V	...	...	...	0.2672	0.3141	0.3581	0.3936	0.4323	0.4687	0.5041	0.5387	0.5747
	H	...	...	...	290.3	303.9	318.9	332.5	343.7	356.0	368.3	380.8	393.5
	S	...	...	...	1.2395	1.2661	1.2890	1.3092	1.3276	1.3446	1.3603	1.3751	1.3892

TABLE 2A-5. PROPERTIES OF SUPERHEATED CARBON DIOXIDE (−75°–450° F.) (*Continued*)

(An abridged table from the work of R. L. Sweigert, Paul Weber, and R. L. Allen, Georgia School of Technology. Published by permission)

Pressure P		Temperature, °F.											
		−75°	−50°	0°	50°	100°	150°	200°	250°	300°	350°	400°	450°
400	V	...			0.2505	0.2961	0.3383	0.3724	0.4095	0.4443	0.4781	0.5110	0.5455
	H				289.4	303.1	318.4	332.1	343.4	355.7	368.1	380.6	393.4
	S				1.2357	1.2627	1.2859	1.3064	1.3250	1.3421	1.3579	1.3728	1.3869
420	V				0.2354	0.2799	0.3203	0.3532	0.3887	0.4222	0.4546	0.4861	0.5190
	H				288.5	302.4	317.9	331.8	343.0	355.4	367.8	308.4	393.2
	S				1.2320	1.2593	1.2828	1.3035	1.3223	1.3395	1.3554	1.3704	1.3846
440	V			...	0.2216	0.2652	0.3040	0.3358	0.3701	0.4022	0.4332	0.4633	0.4950
	H				287.6	301.6	317.4	331.4	342.7	355.1	367.6	380.2	393.0
	S				1.2282	1.2559	1.2797	1.3006	1.3196	1.3370	1.3530	1.3681	1.3823
480	V				0.1975	0.2393	0.2657	0.3054	0.3373	0.3670	0.3958	0.4236	0.4530
	H			...	285.7	300.1	316.4	330.7	342.0	354.5	367.1	379.8	392.7
	S				1.2215	1.2498	1.2741	1.2954	1.3147	1.3324	1.3486	1.3637	1.3781
520	V				0.1772	0.2174	0.2513	0.2795	0.3096	0.3374	0.3641	0.3901	0.4174
	H			...	283.9	298.7	315.4	330.0	341.4	354.0	366.6	379.4	392.3
	S			...	1.2148	1.2438	1.2687	1.2905	1.3102	1.3281	1.3446	1.3599	1.3744
560	V			...	0.1598	0.1986	0.2304	0.2574	0.2858	0.3119	0.3369	0.3613	0.3869
	H			...	282.1	297.2	314.4	329.3	340.7	353.4	366.2	379.0	392.0
	S			...	1.2086	1.2381	1.2635	1.2857	1.3057	1.3239	1.3406	1.3561	1.3708
600	V				0.1452	0.1823	0.2123	0.2383	0.2652	0.2898	0.3135	0.3363	0.3605
	H				280.3	295.7	313.4	328.6	340.0	352.8	365.7	378.6	391.7
	S	...			1.2020	1.2323	1.2583	1.2809	1.3013	1.3198	1.3368	1.3525	1.3677
650	V	...			...	0.1648	0.1928	0.2176	0.2430	0.2661	0.2881	0.3094	0.3323
	H	...			...	293.8	312.2	327.7	339.2	352.1	365.1	378.1	391.5
	S				...	1.2269	1.2534	1.2763	1.2969	1.3156	1.3328	1.3486	1.3632
700	V				...	0.1453	0.1760	0.2000	0.2239	0.2457	0.2664	0.2864	0.3075
	H	...				292.0	310.9	326.9	338.3	351.4	364.5	377.6	390.8
	S	...				1.2216	1.2486	1.2718	1.2927	1.3117	1.3291	1.3450	1.3600
750	V	...				0.1320	0.1615	0.1846	0.2074	0.2281	0.2476	0.2664	0.2865
	H	...				290.1	309.7	326.0	337.5	350.7	363.9	377.0	390.3
	S	...			...	1.2161	1.2436	1.2672	1.2884	1.3076	1.3252	1.3412	1.3563
800	V	...			...	0.1196	0.1483	0.1712	0.1930	0.2126	0.2311	0.2489	0.2681
	H	...			...	288.2	308.4	325.1	336.6	350.0	363.3	376.5	389.9
	S	...			...	1.2111	1.2391	1.2631	1.2846	1.3041	1.3219	1.3380	1.3532
850	V	...			...	0.1089	0.1373	0.1594	0.1803	0.1990	0.2166	0.2335	0.2518
	H	...	...	...		286.4	307.2	324.2	335.8	349.2	362.7	376.0	389.5
	S	...	...		...	1.2061	1.2346	1.2590	1.2808	1.3005	1.3185	1.3348	1.3501
900	V			...	...	0.1000	0.1273	0.1489	0.1690	0.1869	0.2037	0.2198	0.2372
	H	...		...	...	284.5	305.9	323.4	334.9	348.5	362.1	375.5	389.1
	S	...	...		...	1.2010	1.2301	1.2549	1.2770	1.2970	1.3152	1.3317	1.3471

TABLE 2A-5. PROPERTIES OF SUPERHEATED CARBON DIOXIDE (−75°–450° F.) (*Continued*)

(*An abridged table from the work of R. L. Sweigert, Paul Weber, and R. L. Allen, Georgia School of Technology. Published by permission*)

Pressure P		Temperature, °F.											
		−75°	−50°	0°	50°	100°	150°	200°	250°	300°	350°	400°	450°
950	V						0.1183	0.1394	0.1588	0.1761	0.1921	0.2075	0.2243
	H						304.7	322.5	344.1	347.8	361.5	375.0	388.6
	S						1.2260	1.2511	1.2734	1.2937	1.3121	1.3288	1.3443
1000	V						0.1101	0.1310	0.1497	0.1663	0.1819	0.1966	0.2126
	H						303.4	321.6	333.3	347.1	360.9	374.5	388.2
	S						1.2218	1.2472	1.2697	1.2903	1.3089	1.3258	1.3415
1100	V							0.1164	0.1339	0.1495	0.1646	0.1778	0.1925
	H							320.7	331.6	345.7	359.7	373.5	387.3
	S							1.2405	1.2635	1.2844	1.3033	1.3205	1.3364
1200	V							0.1042	0.1208	0.1356	0.1493	0.1621	0.1756
	H							318.4	329.9	344.2	358.5	372.5	386.5
	S							1.2343	1.2579	1.2791	1.2983	1.3158	1.3319
1300	V								0.1100	0.1237	0.1368	0.1488	0.1614
	H								328.2	342.8	357.3	371.4	385.6
	S								1.2530	1.2746	1.2941	1.3117	1.3279
1400	V									0.1136	0.1260	0.1375	0.1492
	H									341.4	356.1	370.4	384.8
	S									1.2703	1.2901	1.3078	1.3242
1500	V									0.1049	0.1167	0.1277	0.1386
	H									339.9	354.9	369.1	383.9
	S									1.2659	1.2861	1.3039	1.3205
1600	V									...	0.1086	0.1191	0.1294
	H									...	353.7	367.6	383.0
	S										1.2822	1.3002	1.3170
1700	V										0.1014	0.1115	0.1213
	H										352.2	366.0	383.2
	S										1.2783	1.2966	1.3135
1800	V											0.1047	0.1140
	H											364.0	382.3
	S											1.2930	1.3101
1900	V												0.1075
	H												381.5
	S												1.3063
2000	V												0.1017
	H												379.4
	S												1.3029

Note: The enthalpy or total heat values are based on an assumed enthalpy above absolute zero of 180 Btu at 32° F. To correlate these values with tables of enthalpy above 32° F. add 180 Btu to the values calculated from 32° F.

TABLE 2A–6. PROPERTIES OF SATURATED METHYL CHLORIDE

Temp. °F. t	Pressure		Volume		Density		Enthalpy from −40°			Entropy from −40°		Temp. °F. t
	Absolute lbs./in.^{2} p	Gage lbs./in.^{2} $g.p.$	Liquid ft.^{3}/lb. v_f	Vapor ft.^{3}/lb. v_g	Liquid lbs./ft.^{3} $1/v_f$	Vapor lbs./ft.^{3} $1/v_g$	Liquid Btu./lb. h_f	Latent Btu./lb. h_{fg}	Vapor Btu./lb. h_g	Liquid Btu./lb.°F. s_f	Vapor Btu./lb.F. s_g	
−80	1.953	25.94*	0.01493	41.08	66.98	0.02434	−13.888	198.64	184.75	−0.0351	0.4882	−80
−70	2.751	24.32*	.01508	29.84	66.31	.03351	−10.521	196.77	186.25	−0.0261	.4790	−70
−60	3.799	22.19*	.01523	22.09	65.66	.04527	− 7.039	194.78	187.74	−0.0172	.4703	−60
−50	5.155	19.43*	.01538	16.64	65.02	.06010	− 3.532	192.72	189.19	−0.0085	.4620	−50
−40	6.878	15.92*	0.01553	12.72	64.39	0.07861	0.000	190.66	190.66	0.0000	0.4544	−40
−38	7.272	15.12*	.01556	12.08	64.27	.08278	.713	190.23	190.95	.0017	.4529	−38
−36	7.684	14.28*	.01559	11.48	64.14	.08712	1.426	189.81	191.23	.0034	.4515	−36
−34	8.115	13.40*	.01562	10.91	64.02	.09166	2.138	189.38	191.51	.0051	.4500	−34
−32	8.566	12.48*	.01565	10.38	63.90	.09639	2.850	188.95	191.80	.0067	.4486	−32
−30	9.036	11.52*	0.01568	9.873	63.78	0.1013	3.562	188.52	192.08	0.0084	0.4472	−30
−28	9.526	10.53*	.01571	9.399	63.65	.1064	4.277	188.09	192.37	.0100	.4458	−28
−26	10.04	9.490*	.01574	8.953	63.53	.1117	4.993	187.65	192.65	.0117	.4445	−26
−24	10.57	8.399*	.01577	8.533	63.41	.1172	5.711	187.22	192.93	.0133	.4431	−24
−22	11.13	7.267*	.01580	8.136	63.29	.1229	6.427	186.78	193.21	.0150	.4418	−22
−20	11.71	6.090*	0.01583	7.761	63.17	0.1289	7.146	186.34	193.49	0.0166	0.4405	−20
−18	12.31	4.866*	.01566	7.408	63.86	.1350	7.863	185.90	193.76	.0183	.4393	−18
−16	12.93	3.594*	.01589	7.074	62.93	.1414	8.584	185.46	194.04	.0199	.4380	−16
−14	13.58	2.268*	.01592	6.758	62.81	.1480	9.307	185.01	194.32	.0215	.4367	−14
−12	14.26	.890*	.01595	6.459	62.70	.1548	10.03	184.56	194.59	.0232	.4355	−12
−10	14.96	.266	0.01598	6.176	62.58	0.1619	10.75	184.11	194.87	0.0247	0.4343	−10
− 8	15.69	.996	.01601	5.908	62.46	.1693	11.48	183.66	195.14	.0263	.4331	− 8
− 6	16.45	1.754	.01604	5.654	62.34	.1769	12.20	183.21	195.42	.0279	.4319	− 6
− 4	17.24	2.540	.01607	5.413	62.23	.1847	12.93	182.76	195.69	.0295	.4307	− 4
− 2	18.05	3.356	.01610	5.185	62.11	.1929	13.66	182.30	195.96	.0311	.4296	− 2

0	18.90	4.201	0.01613	4.969	62.00	0.2013	14.39	181.85	196.23	0.0327	0.4284	0
2	19.77	5.077	.01616	4.763	61.88	.2100	15.12	181.39	196.51	.0343	.4273	2
4	20.68	5.985	.01619	4.568	61.77	.2189	15.85	180.93	196.78	.0359	.4262	4
5	21.15	6.455	.01622	4.471	61.65	.2237	16.21	180.70	196.92	.0367	.4257	5
6	21.62	6.924	.01625	4.379	61.54	.2284	16.58	180.47	197.05	.0375	.4251	6
8	22.59	7.896	.01628	4.206	61.43	.2378	17.31	180.01	197.31	.0390	.4240	8
10	23.60	8.903	0.01631	4.038	61.31	0.2477	18.04	179.53	197.58	0.0406	0.4229	10
12	24.64	9.943	.01634	3.878	61.20	.2579	18.77	179.06	197.83	.0422	.4218	12
14	25.72	11.02	.01637	3.726	61.09	.2684	19.51	178.58	198.09	.0437	.4208	14
16	26.83	12.13	.01640	3.581	60.98	.2792	20.25	178.10	198.34	.0453	.4198	16
18	27.97	13.28	.01644	3.443	60.83	.2904	20.98	177.61	198.59	.0468	.4187	18
20	29.16	14.46	0.01647	3.312	60.72	0.3019	21.73	177.11	198.84	0.0484	0.4177	20
22	30.38	15.69	.01650	3.186	60.61	.3138	22.47	176.61	199.08	.0499	.4166	22
24	31.64	16.95	.01654	3.067	60.46	.3261	23.21	176.11	199.32	.0514	.4156	24
26	32.95	18.25	.01658	2.952	60.31	.3388	23.95	175.61	199.56	.0530	.4146	26
28	34.29	19.60	.01662	2.843	60.17	.3517	24.70	175.10	199.79	.0545	.4136	28
30	35.68	20.98	0.01665	2.739	60.06	0.3650	25.44	174.59	200.03	0.0560	0.4126	30
32	37.11	22.41	.01669	2.640	59.92	.3787	26.18	174.08	200.26	.0575	.4117	32
34	38.58	23.88	.01673	2.546	59.77	.3928	26.93	173.56	200.49	.0590	.4107	34
36	40.09	25.39	.01677	2.455	59.63	.4073	27.67	173.05	200.72	.0605	.4098	36
38	41.65	26.95	.01681	2.369	59.49	.4222	28.42	172.53	200.95	.0621	.4088	38
40	43.25	28.56	0.01684	2.286	59.38	0.4375	29.17	172.00	201.17	0.0636	0.4079	40
42	44.91	30.21	.01688	2.206	59.24	.4532	29.92	171.48	201.40	.0651	.4070	42
44	46.61	31.91	.01692	2.130	59.10	.4694	30.67	170.95	201.62	.0665	.4061	44
46	48.35	33.66	.01696	2.057	58.96	.4861	31.42	170.42	201.84	.0680	.4052	46
48	50.15	35.45	.01700	1.987	58.82	.5033	32.17	169.89	202.06	.0695	.4043	48

* Inches of mercury below one atmosphere.

TABLE 2A-6. PROPERTIES OF SATURATED METHYL CHLORIDE (*Continued*)

Temp. °F. t	Pressure		Volume		Density		Enthalpy from −40°			Entropy from −40°		Temp. °F. t
	Absolute lbs./in.² p	Gage lbs./in.² $g.p.$	Liquid ft.³/lb. v_f	Vapor ft.³/lb. v_g	Liquid lbs./ft.³ $1/v_f$	Vapor lbs./ft.³ $1/v_g$	Liquid Btu./lb. h_f	Latent Btu./lb. h_{fg}	Vapor Btu./lb. h_g	Liquid Btu./lb.°F. s_f	Vapor Btu./lb.F. s_g	
50	51.99	37.29	0.01704	1.920	58.69	0.5208	32.93	169.35	202.28	0.0710	0.4034	50
52	53.88	39.18	.01708	1.856	58.55	.5388	33.68	168.81	202.49	.0725	.4025	52
54	55.83	41.13	.01712	1.794	58.41	.5573	34.44	168.27	202.71	.0740	.4017	54
56	57.83	43.13	.01716	1.735	58.28	.5763	35.19	167.72	202.91	.0754	.4008	56
58	59.88	45.19	.01720	1.679	58.14	.5958	35.95	167.18	203.13	.0769	.3999	58
60	62.00	47.30	0.01724	1.624	58.00	0.6158	36.71	166.62	203.33	0.0784	0.3991	60
62	64.17	49.47	.01728	1.572	57.87	.6362	37.47	166.07	203.54	.0798	.3983	62
64	66.39	51.70	.01732	1.522	57.74	.6572	38.23	165.51	203.74	.0813	.3974	64
66	68.67	53.98	.01736	1.473	57.60	.6788	39.00	164.95	203.95	.0827	.3966	66
68	71.01	56.32	.01740	1.427	57.47	.7008	39.76	164.39	204.15	.0842	.3958	68
70	73.41	58.71	0.01744	1.382	57.34	0.7234	40.52	163.82	204.34	0.0856	0.3950	70
72	75.86	61.17	.01748	1.339	57.21	.7467	41.29	163.24	204.53	.0870	.3941	72
74	78.37	63.68	.01752	1.298	57.08	.7704	42.06	162.66	204.72	.0885	.3933	74
76	80.94	66.25	.01756	1.258	56.95	.7948	42.82	162.08	204.90	.0899	.3925	76
78	83.57	68.87	.01760	1.220	56.82	.8196	43.59	161.50	205.09	.0913	.3918	78
80	86.26	71.56	0.01764	1.183	56.69	0.8451	44.36	160.91	205.27	0.0928	0.3910	80
82	89.01	74.31	.01768	1.148	56.56	.8710	45.13	160.32	205.45	.0942	.3902	82
84	91.82	77.13	.01773	1.114	56.40	.8979	45.90	159.72	205.62	.0956	.3894	84
86	94.70	80.00	.01778	1.081	56.24	.9253	46.67	159.13	205.80	.0970	.3887	86
88	97.64	82.94	.01782	1.049	56.12	.9531	47.44	158.52	205.96	.0984	.3879	88
90	100.6	85.95	0.01786	1.018	55.99	0.9819	48.21	157.92	206.13	0.0998	0.3872	90
92	103.7	89.02	.01791	.9889	55.83	1.011	48.99	157.31	206.30	.1012	.3865	92
94	106.9	92.16	.01796	.9603	55.68	1.041	49.77	156.69	206.46	.1026	.3857	94
96	110.1	95.37	.01800	.9333	55.56	1.072	50.54	156.08	206.62	.1041	.3850	96
98	113.4	98.65	.01804	.9069	55.43	1.103	51.32	155.46	206.78	.1055	.3843	98

100	116.7	102.0	0.01808	.8814	55.31	1.135	52.09	154.86	206.94	0.1069	0.3836	100
102	120.1	105.4	.01813	.8568	55.15	1.167	52.87	154.22	207.09	.1082	.3828	102
104	123.6	108.9	.01818	.8331	55.01	1.200	53.65	153.60	207.25	.1096	.3822	104
106	127.2	112.5	.01823	.8105	54.85	1.234	54.43	152.97	207.40	.1110	.3815	106
108	130.8	116.1	.01828	.7884	54.70	1.268	55.22	152.33	207.55	.1124	.3808	108
110	134.5	119.8	0.01833	.7672	54.55	1.303	56.00	151.70	207.70	0.1138	0.3801	110
112	138.3	123.6	.01838	.7466	54.41	1.339	56.78	151.06	207.84	.1151	.3794	112
114	142.2	127.5	.01843	.7268	54.26	1.376	57.57	150.41	207.98	.1165	.3787	114
116	146.1	131.4	.01848	.7075	54.11	1.414	58.36	149.77	208.13	.1179	.3781	116
118	150.1	135.4	.01853	.6889	53.97	1.452	59.15	149.11	208.26	.1193	.3774	118
120	154.2	139.5	0.01859	.6710	53.79	1.490	59.93	148.46	208.39	0.1206	0.3768	120
122	158.4	143.7	.01865	.6534	53.62	1.530	60.73	147.80	208.53	.1220	.3762	122
124	162.6	147.9	.01870	.6367	53.48	1.571	61.51	147.14	208.65	.1234	.3755	124
126	167.0	152.3	.01875	.6201	53.33	1.613	62.31	146.47	208.78	.1247	.3749	126
128	171.4	156.7	.01881	.6043	53.16	1.655	63.10	145.80	208.90	.1261	.3742	128
130	175.9	161.1	0.01887	.5889	52.99	1.698	63.89	145.13	209.02	0.1274	0.3736	130
132	180.4	165.7	.01893	.5741	52.83	1.742	64.69	144.45	209.14	.1288	.3730	132
134	185.1	170.4	.01898	.5596	52.69	1.787	65.48	143.77	209.25	.1301	.3723	134
136	189.8	175.1	.01904	.5455	52.52	1.833	66.28	143.09	209.37	.1314	.3717	136
138	194.7	180.0	.01909	.5320	52.38	1.880	67.08	142.40	209.48	.1328	.3711	138
140	199.6	184.9	0.01915	.5189	52.22	1.927	67.87	141.71	209.58	0.1341	0.3705	140
150	225.4	210.7	0.01945	.4586	51.41	2.181	71.87	138.23	210.10	0.1407	0.3674	150
160	253.5	238.8	0.01978	.4070	50.56	2.457	75.90	134.66	210.56	0.1473	0.3646	160
170	283.9	269.2	0.02015	.3613	49.63	2.768	79.97	130.96	210.93	0.1538	0.3618	170

TABLE 2A-7. PROPERTIES OF SUPERHEATED METHYL CHLORIDE VAPOR

Temp. °F.	Abs. Pressure, 6 lbs./in.² Gage Pressure, 17.7 in. Vac. (Sat'n. Temp., —44.8° F.)			Abs. Pressure, 7 lbs./in.² Gage Pressure, 15.7 in. Vac. (Sat'n. Temp., —39.4° F.)			Abs. Pressure, 8 lbs./in.² Gage Pressure, 13.6 in. Vac. (Sat'n. Temp., —34.5° F.)			Abs. Pressure, 9 lbs./in.² Gage Pressure, 11.6 in. Vac. (Sat'n. Temp., —30.2° F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(At sat'n.)	(14.45)	(189.96)	(.4580)	(12.52)	(190.75)	(.4539)	(11.06)	(191.44)	(.4504)	(9.911)	(192.07)	(.4473)
−40	14.62	190.77	.4599	.....	.....	.....	.....	.....	.....	.....	.....	.....
−30	14.99	192.52	.4640	12.80	192.34	.4578	11.17	192.17	.4523	9.911	192.10	.4475
−20	15.36	194.27	.4681	13.12	194.12	.4618	11.46	193.97	.4563	10.16	193.82	.4515
−10	15.72	196.06	.4721	13.43	195.92	.4658	11.74	195.78	.4603	10.41	195.64	.4556
0	16.09	197.84	.4760	13.74	197.71	.4698	12.01	197.58	.4643	10.66	197.45	.4595
10	16.45	199.66	.4799	14.06	199.54	.4737	12.29	199.42	.4682	10.91	199.30	.4635
20	16.82	201.48	.4838	14.37	201.37	.4776	12.57	201.26	.4721	11.15	201.15	.4673
30	17.18	203.34	.4876	14.69	203.23	.4814	12.84	203.12	.4760	11.39	203.02	.4712
40	17.55	205.19	.4914	15.00	205.09	.4852	13.11	204.97	.4798	11.63	204.88	.4750
50	17.91	207.10	.4952	15.31	207.00	.4890	13.39	206.90	.4836	11.88	206.80	.4788
60	18.27	209.01	.4989	15.63	208.92	.4927	13.66	208.82	.4873	12.12	208.72	.4825
65	18.45	209.98	.5007	15.78	209.88	.4945	13.79	209.79	.4891	12.24	209.69	.4843
70	18.63	210.95	.5025	15.94	210.85	.4964	13.93	210.76	.4910	12.36	210.67	.4862
80	18.99	212.88	.5061	16.25	212.79	.5000	14.21	212.70	.4946	12.61	212.62	.4899
90	19.35	214.85	.5097	16.56	214.77	.5036	14.48	214.68	.4982	12.85	214.60	.4935
100	19.71	216.82	.5133	16.86	216.74	.5072	14.75	216.66	.5018	13.09	216.58	.4971
110	20.07	218.83	.5169	17.17	218.76	.5108	15.02	218.68	.5054	13.33	218.60	.5007
120	20.42	220.84	.5204	17.48	220.77	.5143	15.29	220.70	.5089	13.58	220.62	.5042
130	20.78	222.89	.5239	17.79	222.82	.5178	15.56	222.75	.5124	13.82	222.68	.5077
140	21.14	224.94	.5274	18.11	224.87	.5212	15.83	224.81	.5159	14.06	224.74	.5112
150	21.50	227.03	.5308	18.42	226.96	.5247	16.10	226.90	.5193	14.30	226.83	.5146
160	21.86	229.11	.5342	18.73	229.05	.5281	16.37	228.99	.5227	14.54	228.93	.5181
170	22.21	231.24	.5376	19.04	231.18	.5315	16.64	231.12	.5261	14.79	231.06	.5215
180	22.57	233.36	.5410	19.35	233.30	.5348	16.91	233.25	.5295	15.03	233.19	.5248
190	22.93	235.52	.5443	19.65	235.47	.5382	17.18	235.41	.5329	15.27	235.36	.5282
200	23.29	237.69	.5476	19.96	237.63	.5415	17.45	237.58	.5362	15.51	237.53	.5315
210	23.64	239.89	.5510	20.26	239.83	.5448	17.72	239.78	.5395	15.75	239.73	.5348
220	24.00	242.09	.5542	20.58	242.04	.5481	17.99	241.99	.5428	15.99	241.94	.5381
230	24.35	244.34	.5575	20.88	244.30	.5514	18.26	244.25	.5460	16.23	244.20	.5414
240	24.71	246.60	.5607	21.19	246.55	.5546	18.52	246.51	.5493	16.47	246.46	.5446
250	25.06	248.88	.5640	21.49	248.83	.5578	18.79	248.79	.5525	16.71	248.74	.5479
260	25.42	251.15	.5672	21.79	251.11	.5610	19.06	251.06	.5557	16.95	251.02	.5511
270	....	.....	.....	22.10	253.44	.5642	19.33	253.40	.5589	17.19	253.36	.5543

Temp. ° F.	Abs. Pressure, 10 lbs./in.² Gage Pressure, 9.6 in. Vac. (Sat'n. Temp., —26.1° F.)			Abs. Pressure, 11 lbs /in.² Gage Pressure, 7.5 in. Vac. (Sat'n. Temp., —22.5° F.)			Abs. Pressure, 12 lbs /in.² Gage Pressure, 5.5 in. Vac. (Sat'n. Temp., —19.0° F.)			Abs. Pressure, 13 lbs./in.² Gage Pressure, 3.5 in. Vac. (Sat'n. Temp., —15.8° F.)		
(At sat'n)	(8.993)	(192.64)	(.4446)	(8.224)	(193.16)	(.4421)	(7.587)	(193.64)	(.4399)	(7.042)	(194.10)	(.4379)
−20	9.124	193.67	.4471	8.271	193.52	.4431	....	.....	....	....	.....	....
−10	9.346	195.50	.4512	8.473	195.36	.4472	7.752	195.21	.4436	7.143	195.08	.4403
0	9.567	197.32	.4552	8.675	197.19	.4512	7.943	197.06	.4476	7.317	196.93	.4443
10	9.788	199.18	.4591	8.877	199.06	.4552	8.131	198.94	.4516	7.489	198.82	.4483
20	10.01	201.04	.4630	9.079	200.93	.4591	8.318	200.82	.4555	7.661	200.71	.4522
30	10.23	202.91	.4669	9.281	202.81	.4630	8.503	202.70	.4594	7.831	202.60	.4561
40	10.45	204.78	.4707	9.483	204.68	.4668	8.688	204.58	.4632	8.001	204.48	.4599
50	10.67	206.70	.4745	9.685	206.60	.4706	8.873	206.51	.4670	8.171	206.41	.4637
60	10.89	208.62	.4782	9.887	208.53	.4744	9.056	208.43	.4708	8.341	208.34	.4675
65	11.00	209.60	.4800	9.988	209.50	.4762	9.147	209.41	.4726	8.426	209.32	.4693
70	11.11	210.58	.4819	10.09	210.48	.4781	9.239	210.39	.4745	8.511	210.30	.4712
80	11.33	212.53	.4856	10.29	212.44	.4818	9.422	212.35	.4782	8.681	212.27	.4749
90	11.55	214.51	.4892	10.49	214.43	.4854	9.605	214.34	.4818	8.851	214.26	.4786
100	11.77	216.50	.4928	10.70	216.42	.4890	9.788	216.34	.4855	9.021	216.26	.4822
110	11.99	218.52	.4964	10.89	218.44	.4926	9.971	218.37	.4890	9.191	218.29	.4858
120	12.21	220.54	.5000	11.09	220.47	.4961	10.15	220.40	.4926	9.361	220.32	.4894
130	12.43	222.61	.5035	11.29	222.54	.4996	10.34	222.47	.4961	9.531	222.40	.4929
140	12.65	224.67	.5069	11.49	224.61	.5031	10.52	224.54	.4996	9.699	224.47	.4964
150	12.86	226.77	.5104	11.69	226.70	.5065	10.70	226.64	.5030	9.867	226.57	.4998
160	13.08	228.86	.5138	11.88	228.80	.5100	10.88	228.74	.5065	10.04	228.68	.5032
170	13.30	231.00	.5172	12.08	230.94	.5134	11.06	230.88	.5099	10.20	230.82	.5066
180	13.52	233.13	.5206	12.28	233.07	.5168	11.24	233.02	.5133	10.37	232.96	.5100
190	13.74	235.30	.5240	12.47	235.25	.5201	11.42	235.19	.5166	10.54	235.14	.5134
200	13.95	237.47	.5273	12.67	237.42	.5235	11.60	237.37	.5200	10.70	237.31	.5168
210	14.17	239.68	.5306	12.87	239.63	.5268	11.78	239.58	.5233	10.87	239.53	.5201
220	14.38	241.89	.5339	13.07	241.84	.5301	11.96	241.79	.5266	11.04	241.74	.5234
230	14.60	244.15	.5372	13.26	244.11	.5334	12.15	244.06	.5299	11.21	244.01	.5267
240	14.81	246.42	.5405	13.46	246.37	.5367	12.33	246.33	.5332	11.37	246.28	.5300
250	15.03	248.70	.5437	13.66	248.65	.5399	12.51	248.61	.5364	11.54	248.57	.5332
260	15.24	250.98	.5469	13.85	250.94	.5431	12.69	250.90	.5396	11.71	250.85	.5364
270	15.46	253.32	.5501	14.05	253.28	.5463	12.87	253.24	.5428	11.87	253.19	.5396
280	15.67	255.66	.5532	14.25	255.62	.5495	13.05	255.38	.5460	12.04	255.53	.5428
290	....	.....	....	....	.....	....	13.23	257.98	.5491	12.21	257.93	.5459

TABLE 2A-7. PROPERTIES OF SUPERHEATED METHYL CHLORIDE VAPOR (*Continued*)

Temp. °F.	Abs. Pressure, 14 lbs./in.² Gage Pressure, 1.4 in. Vac. (Sat'n. Temp., —12.8° F.)			Abs. Pressure, 15 lbs./in.² Gage Pressure, 0.3 lbs./in.² (Sat'n. Temp., —9.9° F.)			Abs. Pressure, 16 lbs./in.² Gage Pressure, 1.3 lbs./in.² (Sat'n. Temp., —7.2° F.)			Abs. Pressure, 18 lbs./in.² Gage Pressure, 3.3 lbs./in.² (Sat'n. Temp., —2.1° F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(At sat'n.)	(6.570)	(194.51)	(.4339)	(6.161)	(194.91)	(.4342)	(5.804)	(195.28)	(.4326)	(5.200)	(195.97)	(.4296)
–10	6.614	194.92	.4371	.....	.....	.....	.....	.....	.....	.....	.....	.....
0	6.777	196.80	.4412	6.313	196.67	.4383	5.907	196.54	.4355	5.227	196.27	.4305
10	6.940	198.70	.4452	6.464	198.58	.4423	6.050	198.45	.4396	5.355	198.20	.4345
20	7.102	200.60	.4491	6.618	200.48	.4462	6.192	200.37	.4435	5.482	200.12	.4385
30	7.262	202.49	.4530	6.766	202.38	.4501	6.333	202.27	.4474	5.608	202.04	.4425
40	7.422	204.38	.4569	6.916	204.28	.4540	6.473	204.18	.4513	5.734	203.96	.4464
50	7.581	206.31	.4607	7.067	206.21	.4578	6.613	206.10	.4552	5.859	205.91	.4502
60	7.740	208.24	.4645	7.215	208.14	.4616	6.753	208.05	.4589	5.984	207.86	.4541
65	7.819	209.22	.4663	7.289	209.13	.4635	6.823	209.04	.4608	6.046	208.85	.4559
70	7.899	210.21	.4682	7.363	210.12	.4654	6.893	210.03	.4627	6.109	209.84	.4578
80	8.057	212.18	.4719	7.511	212.09	.4691	7.033	212.00	.4664	6.234	211.83	.4616
90	8.215	214.18	.4756	7.659	214.09	.4727	7.173	214.01	.4701	6.359	213.84	.4652
100	8.373	216.19	.4792	7.806	216.09	.4764	7.311	216.01	.4737	6.483	215.85	.4689
110	8.531	218.21	.4828	7.953	218.13	.4800	7.449	218.06	.4773	6.607	217.90	.4725
120	8.688	220.25	.4863	8.100	220.17	.4835	7.587	220.10	.4809	6.730	219.95	.4761
130	8.845	222.32	.4899	8.247	222.25	.4871	7.725	222.18	.4844	6.853	222.04	.4796
140	9.002	224.40	.4934	8.394	224.33	.4906	7.863	224.26	.4879	6.976	224.13	.4831
150	9.159	226.51	.4968	8.540	226.44	.4940	8.001	226.38	.4914	7.098	226.25	.4866
160	9.314	228.61	.5003	8.686	228.55	.4975	8.137	228.49	.4949	7.220	228.37	.4901
170	9.469	230.76	.5037	8.832	230.70	.5009	8.273	230.64	.4983	7.342	230.52	.4935
180	9.624	232.90	.5071	8.978	232.85	.5043	8.409	232.79	.5017	7.464	232.67	.4969
190	9.779	235.08	.5105	9.124	235.03	.5077	8.545	234.97	.5051	7.586	234.86	.5003
200	9.934	237.26	.5138	9.268	237.21	.5110	8.681	237.15	.5084	7.707	237.05	.5037
210	10.09	239.48	.5172	9.412	239.43	.5144	8.817	239.38	.5118	7.828	239.27	.5070
220	10.24	241.69	.5205	9.556	241.64	.5177	8.953	241.60	.5151	7.949	241.50	.5104
230	10.40	243.97	.5237	9.700	243.92	.5210	9.089	243.87	.5184	8.070	243.78	.5136
240	10.55	246.24	.5270	9.844	246.19	.5242	9.225	246.14	.5216	8.191	246.05	.5169
250	10.71	248.52	.5302	9.988	248.48	.5275	9.361	248.43	.5249	8.312	248.35	.5202
260	10.86	250.81	.5334	10.13	250.77	.5307	9.497	250.73	.5281	8.433	250.64	.5234
270	11.01	253.15	.5366	10.28	253.11	.5339	9.632	253.07	.5313	8.554	252.98	.5266
280	11.17	255.49	.5398	10.42	255.45	.5371	9.767	255.40	.5345	8.675	255.32	.5298
290	11.32	257.83	.5430	10.56	257.80	.5403	9.902	257.76	.5377	8.796	257.68	.5330
300	.....	.....	.....	10.71	260.16	.5434	10.04	260.12	.5409	8.917	260.04	.5362

Temp. °F.	Abs. Pressure, 20 lbs./in.^{2} Gage Pressure, 5.3 lbs./in.^{2} (Sat'n. Temp., 2.5° F.)			Abs. Pressure, 22 lbs./in.^{2} Gage Pressure, 7.3 lbs./in.^{2} (Sat'n. Temp., 6.8° F.)			Abs. Pressure, 24 lbs./in.^{2} Gage Pressure, 9.3 lbs./in.^{2} (Sat'n. Temp., 10.8° F.)			Abs. Pressure, 26 lbs./in.^{2} Gage Pressure, 11.3 lbs./in.^{2} (Sat'n. Temp., 14.5° F.)		
(At sat'n.)	(4.710)	(196.58)	(.4270)	(4.310)	(197.15)	(.4246)	(3.973)	(197.67)	(.4224)	(3.686)	(198.14)	(.4204)
10	4.801	197.95	.4300	4.346	197.76	.4259	.....	.....	.....	.....	.....	.....
20	4.917	199.90	.4341	4.452	199.65	.4299	4.063	199.41	.4262	3.737	199.15	.4227
30	5.032	201.82	.4380	4.557	201.59	.4340	4.161	201.35	.4301	3.828	201.11	.4267
40	5.146	203.75	.4420	4.661	203.52	.4379	4.259	203.30	.4341	3.918	203.07	.4307
50	5.260	205.71	.4458	4.765	205.50	.4418	4.356	205.29	.4380	4.008	205.08	.4346
60	5.373	207.66	.4496	4.868	207.47	.4457	4.452	207.28	.4419	4.097	207.09	.4385
65	5.429	208.66	.4515	4.919	208.47	.4476	4.499	208.28	.4438	4.141	208.10	.4404
70	5.486	209.66	.4534	4.971	209.47	.4495	4.547	209.29	.4457	4.186	209.11	.4423
80	5.599	211.65	.4572	5.074	211.48	.4533	4.642	211.29	.4495	4.274	211.12	.4461
90	5.711	213.67	.4608	5.177	213.50	.4570	4.737	213.33	.4532	4.362	213.16	.4499
100	5.823	215.69	.4645	5.279	215.53	.4607	4.831	215.37	.4569	4.449	215.20	.4536
110	5.935	217.75	.4681	5.381	217.59	.4643	4.925	217.44	.4606	4.536	217.28	.4573
120	6.046	219.80	.4717	5.483	219.65	.4679	5.019	219.50	.4642	4.623	219.36	.4609
130	6.157	221.90	.4753	5.585	221.75	.4714	5.112	221.61	.4678	4.710	221.47	.4645
140	6.268	223.99	.4788	5.687	223.85	.4749	5.205	223.71	.4713	4.797	223.57	.4680
150	6.379	226.12	.4823	5.789	225.98	.4784	5.298	225.85	.4748	4.883	225.72	.4715
160	6.489	228.24	.4858	5.891	228.11	.4819	5.390	227.99	.4782	4.969	227.86	.4750
170	6.599	230.40	.4892	5.992	230.28	.4853	5.482	230.16	.4818	5.055	230.04	.4785
180	6.709	232.56	.4927	6.094	232.44	.4888	5.574	232.32	.4852	5.141	232.21	.4819
190	6.819	234.75	.4961	6.193	234.64	.4922	5.666	234.53	.4886	5.227	234.41	.4853
200	6.929	236.94	.4994	6.293	236.84	.4956	5.758	236.73	.4920	5.312	236.62	.4887
210	7.038	239.17	.5028	6.393	239.07	.4989	5.849	238.97	.4954	5.397	238.86	.4921
220	7.147	241.40	.5061	6.493	241.30	.5022	5.940	241.20	.4987	5.482	241.10	.4955
230	7.256	243.68	.5094	6.593	243.59	.5055	6.031	243.49	.5020	5.567	243.39	.4988
240	7.365	245.96	.5127	6.693	245.87	.5088	6.122	245.78	.5053	5.652	245.69	.5021
250	7.474	248.26	.5159	6.792	248.17	.5121	6.213	248.08	.5086	5.736	247.99	.5053
260	7.583	250.55	.5192	6.891	250.47	.5153	6.304	250.39	.5118	5.820	250.30	.5086
270	7.692	252.89	.5224	6.990	252.81	.5185	6.393	252.72	.5150	5.904	252.64	.5118
280	7.801	255.23	.5256	7.088	255.15	.5217	6.486	255.06	.5182	5.988	254.98	.5150
290	7.910	257.60	.5287	7.186	257.52	.5249	6.577	257.43	.5214	6.072	257.36	.5182
300	8.019	259.96	.5319	7.284	259.88	.5280	6.668	259.80	.5245	6.155	259.73	.5213
310	8.128	262.36	.5350	7.382	262.29	.5312	6.759	262.21	.5277	6.238	262.14	.5245
320	.....	.....	.....	.....	.....	.....	6.850	264.62	.5308	6.321	264.55	.5276

Table 2A-7. Properties of Superheated Methyl Chloride Vapor (*Continued*)

Temp. °F.	Abs. Pressure, 28 lbs./in.² Gage Pressure, 13.3 lbs./in.² (Sat'n. Temp., 18.0° F.)			Abs. Pressure, 30 lbs./in.² Gage Pressure, 15.3 lbs./in.² (Sat'n. Temp., 21.4° F.)			Abs. Pressure, 32 lbs./in.² Gage Pressure, 17.3 lbs./in.² (Sat'n. Temp., 24.5° F.)			Abs. Pressure, 34 lbs./in.² Gage Pressure, 19.3 lbs./in.² (Sat'n. Temp., 27.6° F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(At sat'n.)	(3.439)	(198.59)	(.4186)	(3.224)	(199.00)	(.4169)	(3.034)	(199.39)	(.4153)	(2.866)	(199.76)	(.4137)
20	3.455	198.89	.4194	.....	.....	.....	.....	.....	.....	.....	.....	.....
30	3.541	200.87	.4235	3.292	200.62	.4205	3.075	200.38	.4176	2.883	200.12	.4149
40	3.626	202.84	.4275	3.373	202.62	.4245	3.151	202.38	.4216	2.955	202.17	.4190
50	3.710	204.87	.4314	3.453	204.66	.4284	3.226	204.44	.4256	3.026	204.22	.4230
60	3.794	206.90	.4353	3.532	206.70	.4324	3.300	206.50	.4295	3.097	206.30	.4269
65	3.835	207.91	.4372	3.571	207.71	.4343	3.337	207.52	.4314	3.132	207.32	.4288
70	3.877	208.92	.4392	3.610	208.73	.4362	3.374	208.54	.4334	3.167	208.35	.4308
80	3.960	210.95	.4430	3.687	210.77	.4400	3.447	210.58	.4372	3.236	210.40	.4346
90	4.042	212.99	.4467	3.764	212.82	.4438	3.520	212.64	.4410	3.305	212.47	.4384
100	4.124	215.04	.4504	3.840	214.87	.4475	3.592	214.70	.4447	3.373	214.54	.4421
110	4.206	217.12	.4541	3.916	216.96	.4512	3.664	216.81	.4485	3.441	216.65	.4459
120	4.287	219.21	.4578	3.992	219.06	.4548	3.736	218.91	.4521	3.509	218.76	.4495
130	4.368	221.32	.4614	4.067	221.18	.4585	3.807	221.03	.4558	3.577	220.89	.4532
140	4.449	223.44	.4649	4.142	223.30	.4620	3.878	223.16	.4593	3.644	223.02	.4563
150	4.529	225.59	.4685	4.217	225.45	.4656	3.949	225.32	.4629	3.711	225.18	.4604
160	4.609	227.73	.4720	4.292	227.61	.4691	4.020	227.48	.4664	3.778	227.35	.4639
170	4.689	229.91	.4755	4.367	229.79	.4726	4.090	229.67	.4699	3.845	229.55	.4674
180	4.768	232.09	.4789	4.442	231.97	.4761	4.160	231.86	.4734	3.911	231.74	.4709
190	4.847	234.30	.4823	4.517	234.19	.4795	4.230	234.08	.4768	3.977	233.96	.4743
200	4.926	236.51	.4857	4.591	236.40	.4829	4.300	236.30	.4802	4.043	236.19	.4777
210	5.005	238.76	.4891	4.665	238.65	.4862	4.370	238.55	.4836	4.109	238.45	.4811
220	5.084	241.00	.4924	4.739	240.90	.4896	4.439	240.80	.4870	4.174	240.70	.4845
230	5.163	243.30	.4957	4.813	243.20	.4929	4.508	243.11	.4903	4.239	243.01	.4878
240	5.241	245.59	.4990	4.887	245.50	.4962	4.577	245.41	.4936	4.304	245.32	.4911
250	5.319	247.90	.5023	4.961	247.82	.4995	4.646	247.73	.4969	4.369	247.64	.4944
260	5.397	250.21	.5056	5.034	250.13	.5028	4.715	250.04	.5002	4.434	249.96	.4977
270	5.475	252.56	.5088	5.107	252.48	.5060	4.784	252.39	.5034	4.498	252.31	.5009
280	5.553	254.90	.5120	5.180	254.82	.5092	4.852	254.74	.5066	4.562	254.66	.5041
290	5.631	257.28	.5152	5.253	257.20	.5124	4.920	257.13	.5098	4.626	257.05	.5073
300	5.709	259.66	.5184	5.326	259.58	.5156	4.988	259.51	.5130	4.690	259.43	.5105
310	5.787	262.07	.5215	5.399	262.00	.5187	5.056	261.92	.5161	4.754	261.85	.5137
320	5.865	264.48	.5246	5.472	264.41	.5218	5.124	264.34	.5192	4.818	264.27	.5168
330	.....	.....	.....	5.545	266.85	.5249	5.192	266.79	.5223	4.882	266.72	.5199

Temp. ° F.	Abs. Pressure, 36 lbs./in.² Gage Pressure, 21.3 lbs./in.² (Sat'n. Temp., 30.5° F.)			Abs. Pressure, 38 lbs./in.² Gage Pressure, 23.3 lbs./in.² (Sat'n. Temp., 33.2° F.)			Abs. Pressure, 40 lbs./in.² Gage Pressure, 25 3 lbs./in.² (Sat'n. Temp., 35.9° F.)			Abs. Pressure, 45 lbs./in.² Gage Pressure, 30.3 lbs./in.² (Sat'n. Temp., 42.1° F.)		
(At sat'n.)	(2.717)	(200.10)	(.4123)	(2.582)	(200.43)	(.4110)	(2.461)	(200.73)	(.4097)	(2.201)	(201.45)	(.4069)
40	2.781	201.89	.4162	2.625	201.63	.4138	2.485	201.38	.4115	.....	.....	.....
50	2.849	203.99	.4203	2.690	203.76	.4179	2.547	203.54	.4156	2.244	202.99	.4102
60	2.916	206.10	.4243	2.754	205.90	.4219	2.608	205.69	.4196	2.300	205.08	.4143
65	2.949	207.13	.4262	2.785	206.93	.4239	2.638	206.73	.4216	2.327	206.15	.4163
70	2.982	208.16	.4282	2.817	207.96	.4259	2.668	207.77	.4236	2.355	207.22	.4183
80	3.048	210.21	.4321	2.880	210.03	.4297	2.729	209.84	.4275	2.410	209.37	.4222
90	3.113	212.29	.4359	2.942	212.11	.4336	2.788	211.94	.4313	2.464	211.49	.4261
100	3.178	214.37	.4397	3.004	214.20	.4373	2.847	214.03	.4351	2.518	213.61	.4299
110	3.243	216.49	.4434	3.066	216.33	.4411	2.906	216.17	.4389	2.571	215.77	.4337
120	3.307	218.61	.4471	3.127	218.46	.4448	2.964	218.32	.4426	2.624	217.92	.4375
130	3.371	220.75	.4508	3.188	220.60	.4484	3.022	220.46	.4463	2.676	220.08	.4412
140	3.435	222.88	.4544	3.249	222.74	.4521	3.080	222.60	.4499	2.728	222.24	.4448
150	3.499	225.05	.4579	3.310	224.92	.4557	3.138	224.78	.4535	2.780	224.44	.4484
160	3.562	227.22	.4615	3.370	227.09	.4592	3.195	226.96	.4570	2.831	226.64	.4520
170	3.625	229.42	.4650	3.430	229.30	.4627	3.252	229.18	.4606	2.882	228.87	.4556
180	3.688	231.62	.4685	3.490	231.50	.4662	3.309	231.38	.4641	2.933	231.09	.4591
190	3.751	233.85	.4719	3.550	233.74	.4697	3.366	233.62	.4675	2.984	233.34	.4626
200	3.813	236.08	.4754	3.609	235.97	.4731	3.423	235.86	.4710	3.034	235.59	.4661
210	3.875	238.34	.4788	3.668	238.24	.4765	3.479	238.13	.4744	3.084	237.87	.4695
220	3.937	240.60	.4821	3.727	240.50	.4799	3.535	240.40	.4778	3.134	240.15	.4729
230	3.999	242.92	.4855	3.786	242.82	.4832	3.591	242.72	.4811	3.184	242.48	.4763
240	4.061	245.23	.4888	3.844	245.14	.4866	3.647	245.04	.4845	3.234	244.81	.4796
250	4.122	247.55	.4921	3.902	247.46	.4899	3.703	247.37	.4878	3.284	247.15	.4829
260	4.183	249.87	.4953	3.960	249.79	.4931	3.759	249.70	.4910	3.334	249.48	.4862
270	4.244	252.23	.4986	4.018	252.15	.4964	3.814	252.06	.4943	3.384	251.85	.4895
280	4.305	254.58	.5018	4.076	254.50	.4996	3.869	254.42	.4975	3.433	254.22	.4927
290	4.366	256.97	.5050	4.134	256.89	.5028	3.924	256.82	.5007	3.482	256.62	.4959
300	4.427	259.36	.5082	4.192	259.28	.5060	3.979	259.21	.5039	3.531	259.02	.4991
310	4.488	261.78	.5114	4.250	261.71	.5092	4.034	261.64	.5071	3.580	261.45	.5023
320	4.549	264.20	.5145	4.308	264.13	.5123	4.089	264.06	.5102	3.629	263.88	.5054
330	4.610	266.67	.5176	4.366	266.60	.5154	4.144	266.53	.5133	3.678	266.36	.5085
340	4.671	269.14	.5207	4.424	269.07	.5185	4.199	269.00	.5164	3.727	268.83	.5116
350	.....	.....	.....	.....	.....	.....	.....	.....	.....	3.776	271.34	.5147

TABLE 2A-7. PROPERTIES OF SUPERHEATED METHYL CHLORIDE VAPOR (*Continued*)

Temp. °F.	Abs. Pressure, 50 lbs/in.², Gage Pressure, 35.3 lbs./in.² (Sat'n. Temp., 47.8° F.)			Abs. Pressure, 55 lbs./in.², Gage Pressure, 40.3 lbs/in.² (Sat'n. Temp., 53.1° F.)			Abs Pressure, 60 lbs./in², Gage Pressure, 45.3 lbs/in.² (Sat'n. Temp., 58.1° F.)			Abs. Pressure, 65 lbs./in.², Gage Pressure, 50.3 lbs./in.² (Sat'n. Temp., 62.7° F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(At sat'n.)	(1.992)	(202.09)	(.4043)	(1.820)	(202.66)	(.4019)	(1.676)	(203.17)	(.3998)	(1.552)	(203.65)	(.3978)
50	2.003	202.55	.4053	....	.....	.....	.....	.....	.....	....	.....	.....
60	2.054	204.65	.4094	1.852	204.11	.4049	1.684	203.49	.4008	....	.....	.....
65	2.079	205.71	.4114	1.875	205.18	.4069	1.705	204.60	.4028	1.561	204.13	.3988
70	2.104	206.77	.4134	1.898	206.26	.4090	1.727	205.71	.4049	1.581	205.17	.4010
80	2.154	208.89	.4174	1.944	208.40	.4130	1.770	207.92	.4089	1.622	207.43	.4051
90	2.203	211.03	.4213	1.989	210.57	.4170	1.812	210.11	.4129	1.662	209.64	.4092
100	2.252	213.18	.4252	2.034	212.74	.4209	1.854	212.30	.4169	1.701	211.86	.4131
110	2.300	215.35	.4290	2.079	214.92	.4248	1.895	214.50	.4208	1.740	214.08	.4171
120	2.348	217.52	.4328	2.123	217.11	.4286	1.936	216.69	.4246	1.778	216.31	.4210
130	2.396	219.70	.4366	2.167	219.32	.4323	1.977	218.93	.4284	1.816	218.55	.4248
140	2.443	221.88	.4402	2.211	221.52	.4361	2.017	221.16	.4322	1.854	220.80	.4286
150	2.490	224.10	.4439	2.254	223.76	.4397	2.057	223.41	.4359	1.891	223.06	.4323
160	2.537	226.32	.4475	2.297	225.99	.4434	2.097	225.66	.4396	1.928	225.33	.4360
170	2.584	228.55	.4511	2.340	228.24	.4470	2.137	227.92	.4432	1.965	227.61	.4397
180	2.630	230.79	.4546	2.383	230.49	.4505	2.176	230.19	.4468	2.002	229.88	.4433
190	2.676	233.05	.4581	2.425	232.77	.4541	2.215	232.48	.4503	2.038	232.19	.4468
200	2.722	235.32	.4616	2.467	235.04	.4576	2.254	234.77	.4538	2.074	234.49	.4504
210	2.768	237.61	.4650	2.509	237.35	.4610	2.293	237.08	.4573	2.110	236.82	.4539
220	2.813	239.90	.4684	2.551	239.65	.4644	2.331	239.40	.4608	2.146	239.14	.4573
230	2.858	242.24	.4718	2.593	242.00	.4678	2.369	241.75	.4642	2.182	241.51	.4608
240	2.903	244.58	.4752	2.634	244.35	.4712	2.407	244.11	.4676	2.217	243.88	.4642
250	2.948	246.92	.4785	2.675	246.70	.4746	2.445	246.47	.4709	2.252	246.25	.4675
260	2.993	249.27	.4818	2.716	249.05	.4779	2.483	248.83	.4742	2.287	248.62	.4709
270	3.038	251.65	.4851	2.757	251.43	.4811	2.521	251.22	.4775	2.322	251.01	.4742
280	3.083	254.02	.4884	2.798	253.82	.4844	2.559	253.61	.4808	2.357	253.41	.4774
290	3.128	256.43	.4916	2.839	256.23	.4876	2.597	256.03	.4840	2.392	255.84	.4807
300	3.173	258.83	.4948	2.880	258.65	.4908	2.634	258.46	.4872	2.427	258.27	.4839
310	3.217	261.27	.4980	2.921	261.09	.4940	2.671	260.91	.4904	2.462	260.72	.4871
320	3.261	263.71	.5011	2.962	263.53	.4972	2.708	263.35	.4936	2.497	263.18	.4903
330	3.305	266.18	.5043	3.002	266.01	.5003	2.745	265.83	.4967	2.531	265.66	.4934
340	3.349	268.65	.5074	3.042	268.48	.5034	2.782	268.31	.4999	2.565	268.15	.4965
350	3.393	271.17	.5105	3.082	270.99	.5065	2.819	270.82	.5030	2.599	270.66	.4996
360	.....	.....	.....	3.122	273.49	.5096	2.856	273.33	.5061	2.633	273.18	.5027
370	.....	.....	.....	.....	.....	.....	.....	.....	.....	2.667	275.72	.5058

Temp. °F.	Abs. Pressure, 70 lbs /in.² Gage Pressure, 55.3 lbs /in.² (Sat'n. Temp., 67.1° F.)			Abs Pressure, 75 lbs./in.² Gage Pressure, 60.3 lbs./in.² (Sat'n. Temp., 71.3° F.)			Abs. Pressure, 80 lbs./in.² Gage Pressure, 65.3 lbs /in.² (Sat'n. Temp., 75 3° F.)			Abs. Pressure, 90 lbs./in.² Gage Pressure 75 3 lbs /in.² (Sat'n. Temp , 82.7° F.)		
(At sat'n.)	(1.446)	(204.08)	(.3960)	(1.354)	(204.48)	(.3943)	(1.272)	(204.84)	(.3927)	(1.136)	(205.52)	(.3898)
70	1.458	204.72	.3974	....	.....	.....	.....	.....	.....	....	.....	.....
80	1.496	206.93	.4015	1.385	206.40	.3981	1.289	205.85	.3949	....	.....	.....
90	1.533	209.17	.4056	1.420	208.68	.4022	1.323	208.17	.3991	1.158	207.18	.3931
100	1.570	211.41	.4096	1.455	210.96	.4063	1.356	210.50	.4032	1.189	209.57	.3973
110	1.606	213.64	.4136	1.490	213.20	.4103	1.389	212.76	.4073	1.220	211.87	.4015
120	1.642	215.86	.4175	1.524	215.44	.4143	1.421	215.02	.4113	1.250	214.18	.4055
130	1.678	218.14	.4214	1.558	217.75	.4182	1.453	217.35	.4152	1.279	216.55	.4096
140	1.713	220.43	.4253	1.592	220.05	.4221	1.485	219.68	.4191	1.308	218.92	.4135
150	1.748	222.71	.4290	1.625	222.36	.4259	1.516	222.00	.4229	1.336	221.28	.4174
160	1.783	224.99	.4327	1.658	224.66	.4296	1.547	224.32	.4267	1.364	223.64	.4212
170	1.818	227.28	.4364	1.691	226.97	.4333	1.578	226.64	.4304	1.392	225.99	.4250
180	1.852	229.57	.4400	1.723	229.27	.4370	1.608	228.96	.4341	1.419	228.34	.4287
190	1.886	231.89	.4436	1.755	231.60	.4406	1.638	231.30	.4377	1.446	230.71	.4324
200	1.920	234.21	.4471	1.787	233.93	.4441	1.668	233.65	.4413	1.473	233.08	.4360
210	1.954	236.55	.4506	1.819	236.28	.4476	1.698	236.01	.4448	1.500	235.46	.4396
220	1.987	238.89	.4541	1.850	238.63	.4511	1.728	238.37	.4483	1.527	237.85	.4431
230	2.021	241.26	.4576	1.881	241.02	.4546	1.758	240.77	.4518	1.554	240.27	.4466
240	2.053	243.64	.4610	1.912	243.40	.4580	1.788	243.16	.4552	1.581	242.68	.4501
250	2.086	246.02	.4644	1.943	245.79	.4614	1.817	245.56	.4586	1.607	245.10	.4536
260	2.119	248.39	.4677	1.974	248.17	.4648	1.846	247.95	.4620	1.633	247.51	.4569
270	2.152	250.80	.4710	2.005	250.59	.4681	1.875	250.37	.4654	1.659	249.94	.4603
280	2.185	253.20	.4743	2.035	253.00	.4714	1.904	252.79	.4687	1.685	252.38	.4636
290	2.218	255.64	.4776	2.065	255.44	.4747	1.933	255.24	.4720	1.711	254.84	.4669
300	2.250	258.08	.4808	2.095	257.89	.4779	1.961	257.69	.4752	1.737	257.31	.4702
310	2.282	260.54	.4840	2.125	260.35	.4811	1.989	260.17	.4784	1.763	259.80	.4734
320	2.314	263.00	.4872	2.155	262.82	.4843	2.017	262.64	.4816	1.788	262.29	.4767
330	2.346	265.49	.4904	2.185	265.32	.4875	2.045	265.14	.4848	1.813	264.80	.4798
340	2.378	267.98	.4935	2.215	267.81	.4906	2.073	267.64	.4879	1.838	267.31	.4830
350	2.410	270.50	.4966	2.245	270.34	.4938	2.101	270.17	.4911	1.863	269.85	.4862
360	2.442	273.02	.4997	2.275	272.86	.4969	2.129	272.70	.4942	1.888	272.39	.4893
370	2.474	275.57	.5028	2.305	275.44	.5000	2.157	275.28	.4973	1.913	274.97	.4924
380	.....	.....	.....	2.335	278.02	.5030	2.185	277.86	.5004	1.938	277.55	.4955
390	.....	.....	.....	.....	.....	.....	.....	.....	.....	1.963	280.18	.4985

TABLE 2A-7. PROPERTIES OF SUPERHEATED METHYL CHLORIDE VAPOR (*Continued*)

Temp. °F.	Abs. Pressure, 100 lbs./in.² Gage Pressure, 85.3 lbs./in.² (Sat'n. Temp., 89.6° F.)			Abs. Pressure, 110 lbs./in.² Gage Pressure, 95.3 lbs./in.² (Sat'n. Temp., 95.9° F.)			Abs. Pressure, 120 lbs./in.² Gage Pressure, 105.3 lbs./in.² (Sat'n. Temp., 101.9° F.)			Abs. Pressure, 130 lbs./in.² Gage Pressure, 115.3 lbs./in.² (Sat'n. Temp., 107.5° F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(At sat'n.)	(1.025)	(206.11)	(.3872)	(.934)	(206.63)	(.3849)	(.858)	(207.10)	(.3827)	(.793)	(207.53)	(.3808)
90	1.026	206.21	.3877	....	.....	.....	.....	.....	.....	.....	.....	.....
100	1.055	208.58	.3920	.946	207.54	.3870	.....	.....	.....	.....	.....	.....
110	1.083	210.96	.3962	.972	210.01	.3913	.878	209.12	.3867	.799	208.16	.3824
120	1.111	213.33	.4003	.998	212.47	.3955	.903	211.61	.3910	.823	210.71	.3867
130	1.138	215.74	.4044	1.023	214.92	.3996	.927	214.09	.3952	.846	213.23	.3909
140	1.165	218.15	.4084	1.048	217.37	.4037	.951	216.57	.3993	.868	215.76	.3951
150	1.191	220.55	.4124	1.072	219.80	.4077	.974	219.04	.4034	.890	218.27	.3992
160	1.217	222.94	.4163	1.096	222.24	.4116	.996	221.51	.4074	.911	220.78	.4033
170	1.243	225.33	.4201	1.120	224.65	.4155	1.019	223.97	.4113	.933	223.27	.4073
180	1.268	227.71	.4239	1.143	227.07	.4194	1.041	226.42	.4152	.953	225.76	.4112
190	1.293	230.10	.4276	1.166	229.49	.4231	1.062	228.88	.4190	.973	228.25	.4151
200	1.318	232.50	.4312	1.189	231.92	.4268	1.083	231.33	.4228	.993	230.73	.4189
210	1.343	234.91	.4349	1.212	234.36	.4305	1.104	233.79	.4265	1.013	233.22	.4227
220	1.367	237.32	.4384	1.235	236.79	.4341	1.125	236.25	.4301	1.033	235.71	.4264
230	1.391	239.76	.4420	1.257	239.25	.4377	1.146	238.74	.4337	1.052	238.22	.4301
240	1.415	242.20	.4455	1.279	241.71	.4412	1.167	241.22	.4373	1.071	240.72	.4336
250	1.439	244.63	.4489	1.301	244.16	.4447	1.187	243.69	.4408	1.090	243.21	.4372
260	1.463	247.06	.4523	1.323	246.61	.4481	1.207	246.16	.4443	1.109	245.70	.4407
270	1.487	249.51	.4557	1.345	249.08	.4516	1.227	248.64	.4477	1.128	248.20	.4441
280	1.511	251.96	.4591	1.367	251.54	.4549	1.247	251.12	.4511	1.147	250.70	.4475
290	1.534	254.44	.4624	1.389	254.04	.4583	1.267	253.64	.4545	1.166	253.23	.4509
300	1.557	256.92	.4657	1.410	256.54	.4616	1.287	256.15	.4578	1.184	255.75	.4543
310	1.580	259.43	.4689	1.431	259.05	.4648	1.307	258.67	.4611	1.202	258.29	.4576
320	1.603	261.93	.4722	1.452	261.56	.4681	1.327	261.20	.4643	1.220	260.83	.4608
330	1.626	264.45	.4754	1.473	264.10	.4713	1.346	263.75	.4676	1.238	263.39	.4641
340	1.649	266.97	.4786	1.494	266.63	.4745	1.365	266.29	.4708	1.256	265.95	.4673
350	1.672	269.52	.4817	1.515	269.19	.4777	1.384	268.87	.4740	1.274	268.54	.4705
360	1.695	272.07	.4849	1.536	271.75	.4808	1.403	271.44	.4771	1.292	271.12	.4737
370	1.717	274.66	.4880	1.557	274.35	.4840	1.422	274.03	.4803	1.310	273.72	.4769
380	1.739	277.25	.4911	1.578	276.94	.4871	1.441	276.63	.4834	1.328	276.33	.4800
390	1.761	279.87	.4942	1.598	279.55	.4902	1.460	279.25	.4865	1.345	278.96	.4831
400	.....	.....	.....	1.618	282.16	.4932	1.479	281.87	.4896	1.362	281.59	.4862
410	.....	.....	.....	.....	.....	.....	1.498	284.52	.4926	1.379	284.24	.4893

Temp. ° F.	Abs Pressure, 140 lbs./in ^{2} Gage Pressure, 125.3 lbs /in.^{2} (Sat'n. Temp , 112.9° F)			Abs. Pressure, 150 lbs /in ^{2} Gage Pressure, 135 3 lbs /in.^{2} (Sat'n. Temp., 117 9° F.)			Abs. Pressure, 160 lbs /in.^{2} Gage Pressure, 145 3 lbs /in.^{2} (Sat'n. Temp., 122 8° F.)			Abs. Pressure, 180 lbs /in.^{2} Gage Pressure, 165.3 lbs /in.^{2} (Sat'n. Temp., 131.9° F.)		
(At sat'n.)	(738)	(207 91)	(.3790)	(.689)	(208 27)	(3773)	(647)	(208.59)	(.3757)	(.575)	(209.15)	(.3728)
120	.754	209.70	.3825	.694	208.68	.3785	....	.....	....	.....	.....	....
130	.776	212.32	.3868	.714	211.39	.3830	.661	210.54	.3793	.....	.....	....
140	.796	214.94	.3911	.735	214.09	.3874	.681	213.24	.3837	.590	211.42	.3768
150	.818	217.48	.3954	.755	216.68	.3917	.700	215.87	.3881	.608	214.17	.3814
160	.838	220.03	.3995	.774	219.27	.3959	.719	218.50	.3924	.626	216.92	.3858
170	.858	222.56	.4036	.793	221.84	.4000	.737	221.11	.3966	.642	219.62	.3902
180	.877	225.09	.4076	.812	224.41	.4041	.754	223.73	.4007	.658	222.32	.3944
190	.896	227.61	.4115	.830	226.97	.4081	.772	226.31	.4048	.675	224.98	.3986
200	.915	230.13	.4154	.848	229.52	.4120	.789	228.90	.4087	.691	227.64	.4027
210	.934	232.65	.4192	.866	232.07	.4158	.806	231.48	.4126	.706	230.28	.4067
220	.953	235.17	.4229	.883	234.61	.4196	.823	234.05	.4164	.722	232.92	.4106
230	.971	237.70	.4266	.901	237.17	.4233	.839	236.63	.4202	.737	235.55	.4145
240	.989	240.23	.4302	.917	239.72	.4270	.855	239.21	.4239	.752	238.17	.4182
250	1.007	242.73	.4338	.935	242.25	.4306	.872	241.76	.4275	.766	240.77	.4219
260	1.024	245.24	.4373	.952	244.77	.4341	.888	244.30	.4311	.781	243.36	.4255
270	1.042	247.76	.4407	.968	247.31	.4376	.903	246.86	.4346	.795	245.95	.4291
280	1.060	250.28	.4442	.984	249.85	.4411	.919	249.42	.4381	.809	248.54	.4326
290	1.077	252.82	.4476	1.000	252.40	.4445	.934	251.99	.4415	.823	251.15	.4361
300	1.094	255.36	.4510	1.017	254.96	.4479	.950	254.56	.4449	.837	253.75	.4395
310	1.111	257.91	.4543	1.033	257.53	.4512	.965	257.14	.4483	.851	256.36	.4429
320	1.128	260.46	.4576	1.049	260.10	.4545	.980	259.72	.4516	.865	258.97	.4463
330	1.145	263.04	.4609	1.065	262.68	.4578	.995	262.32	.4549	.878	261.60	.4496
340	1.162	265.61	.4641	1.081	265.27	.4610	1.010	264.92	.4582	.892	264.22	.4529
350	1.179	268.21	.4673	1.097	267.87	.4643	1.025	267.54	.4614	.906	266.86	.4562
360	1.196	270.80	.4705	1.113	270.48	.4675	1.040	270.15	.4647	.919	269.50	.4595
370	1.213	273.41	.4737	1.129	273.10	.4707	1.055	272.78	.4679	.933	272.15	.4627
380	1.230	276.02	.4768	1.145	275.72	.4738	1.070	275.42	.4710	.946	274.80	.4659
390	1.247	278.66	.4799	1.161	278.37	.4770	1.085	278.07	.4742	.959	277.48	.4691
400	1.264	281.30	.4830	1.176	281.02	.4801	1.100	280.73	.4773	.972	280.15	.4722
410	1.280	284.01	.4861	1.191	283.73	.4832	1.114	283.44	.4805	.985	282.88	.4753
420	1.296	286.71	.4892	1.206	286.43	.4863	1.128	286.16	.4836	.999	285.60	.4784
430	....	.....	....	....	.....	....	1.142	288.93	.4866	1.011	288.33	.4815
440	....	.....	....	....	.....	....	....	.....	....	1.024	291.05	.4845

Temp. ° F.	Abs. Pressure, 200 lbs./in.² Gage Pressure, 185.3 lbs./in.² (Sat'n. Temp., 140.3° F.)			Abs. Pressure, 220 lbs./in.² Gage Pressure, 205.3 lbs./in.² (Sat'n. Temp., 148.0° F.)			Abs. Pressure, 240 lbs./in.² Gage Pressure, 225.3 lbs./in.² (Sat'n. Temp., 155.3° F.)			Abs. Pressure, 260 lbs./in.² Gage Pressure, 245.3 lbs./in.² (Sat'n. Temp., 162.3° F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(At sat'n.)	(.517)	(209.60)	(.3702)	(.469)	(209.98)	(.3678)	(.430)	(210.32)	(.3657)	(.396)	(210.62)	(.3637)
150	.533	212.41	.3749	.472	210.58	.3690	....	.....	....	...	.....	....
160	.551	215.30	.3796	.489	213.60	.3739	.437	211.75	.3683	...	.....	....
170	.566	218.09	.3842	.504	216.49	.3785	.451	214.79	.3732	.406	213.04	.3679
180	.582	220.87	.3886	.519	219.38	.3831	.466	217.82	.3779	.421	216.18	.3728
190	.597	223.61	.3929	.533	222.20	.3875	.480	220.73	.3824	.434	219.20	.3775
200	.612	226.35	.3971	.547	225.02	.3918	.493	223.64	.3868	.447	222.22	.3820
210	.626	229.05	.4012	.561	227.79	.3960	.506	226.49	.3911	.459	225.15	.3865
220	.641	231.75	.4052	.574	230.56	.4001	.519	229.33	.3953	.471	228.08	.3908
230	.654	234.43	.4091	.587	233.30	.4041	.531	232.13	.3994	.483	230.95	.3950
240	.668	237.12	.4129	.600	236.03	.4080	.543	234.93	.4034	.495	233.81	.3991
250	.682	239.75	.4167	.613	238.72	.4118	.555	237.67	.4073	.506	236.60	.4031
260	.695	242.39	.4204	.625	241.40	.4156	.566	240.40	.4111	.517	239.38	.4070
270	.708	245.02	.4240	.632	244.07	.4193	.578	243.11	.4149	.528	242.14	.4108
280	.721	247.65	.4276	.650	246.74	.4230	.590	245.82	.4186	.539	244.90	.4145
290	.734	250.29	.4311	.662	249.42	.4265	.601	248.54	.4222	.549	247.66	.4182
300	.747	252.93	.4346	.674	252.10	.4301	.612	251.26	.4258	.560	250.41	.4218
310	.760	255.58	.4380	.685	254.78	.4336	.623	258.97	.4293	.570	253.15	.4254
320	.772	258.21	.4414	.697	257.45	.4370	.634	256.67	.4328	.581	255.89	.4289
330	.785	260.86	.4448	.708	260.12	.4404	.645	259.37	.4363	.591	258.62	.4324
340	.797	263.51	.4481	.720	262.80	.4438	.655	262.08	.4397	.601	261.35	.4359
350	.810	266.17	.4515	.731	265.48	.4471	.666	264.79	.4430	.611	264.09	.4393
360	.822	268.84	.4547	.743	268.17	.4504	.677	267.50	.4464	.621	266.82	.4426
370	.834	271.51	.4580	.754	270.87	.4537	.687	270.22	.4497	.631	269.56	.4460
380	.847	274.19	.4612	.765	273.56	.4569	.697	272.94	.4529	.640	272.31	.4493
390	.859	276.88	.4644	.776	276.28	.4601	.708	275.67	.4562	.650	275.05	.4525
400	.870	279.59	.4676	.787	278.99	.4633	.718	278.40	.4594	.659	277.80	.4558
410	.883	282.31	.4707	.798	281.74	.4665	.729	281.17	.4626	.669	280.60	.4590
420	.895	285.05	.4738	.810	284.50	.4696	.739	283.94	.4658	.679	283.39	.4621
430	.906	287.79	.4769	.820	287.25	.4727	.748	286.71	.4689	.688	286.17	.4653
440	.918	290.52	.4800	.831	290.00	.4758	.758	289.48	.4720	.697	288.96	.4684

SULPHUR DIOXIDE

TABLE 2A–8. PROPERTIES OF SATURATED SULPHUR DIOXIDE

(Arranged by American Society of Refrigerating Engineers, data by David L. Fiske. Published by permission)

Tem.	Pressure		Volume		Density		Enthalpy Above − 40°			Entropy From − 40°		
°F. t	Abs. lb./in.² p	Gage lb./in.² gp	Liquid ft.³/lb. v	Vapor ft.³/lb. V	Liquid lb./ft.³ $1/v$	Vapor lb./ft.³ $1/V$	Liquid Btu./lb. h	Latent† Btu./lb. L	Vapor Btu./lb. H	Liquid Btu./lb.°F. s	Evap. Btu./lb.°F. L/T	Vapor Btu./lb.°F. S
−40	3.136	23.54*	0.010440	22.42	95.79	0.04460	0.00	178.61	178.61	0.00000	0.42562	0.42562
−35	3.693	22.41*	.010486	19.23	95.36	.05200	1.45	177.82	179.27	.00334	.41875	.42209
−30	4.331	21.10*	.010532	16.56	94.94	.06039	2.93	176.97	179.90	.00674	.41190	.41864
−25	5.058	19.63*	0.010580	14.31	94.52	0.06988	4.44	176.06	180.50	0.01016	0.40509	0.41525
−20	5.883	17.93*	.010627	12.42	94.10	.08119	5.98	175.09	181.07	.01366	.39826	.41192
−15	6.814	16.05*	.010674	10.81	93.68	.09250	7.56	174.06	181.62	.01719	.39146	.40865
−10	7.863	13.91*	.010721	9.44	93.27	.1025	9.16	172.97	182.13	.02075	.38469	.40544
− 5	9.033	11.52*	.010770	8.28	92.85	.1203	10.79	171.83	182.62	.02443	.37795	.40228
0	10.35	8.85*	0.010820	7.289	92.42	0.1374	12.44	170.63	183.07	0.02795	0.37122	0.39917
1	10.63	8.27*	.010830	7.099	92.33	.1408	12.79	170.38	183.17	.02869	.36987	.39856
2	10.91	7.34*	.010840	6.923	92.25	.1444	13.12	170.13	183.25	.02941	.36853	.39794
3	11.20	7.11*	.010850	6.751	92.16	.1481	13.45	169.88	183.33	.03013	.36719	.39732
4	11.50	6.50*	.010860	6.584	92.08	.1591	13.78	169.63	183.41	.03084	.36586	.39670
5‡	11.81	5.87*	0.010870	6.421	92.00	0.1558	14.11	169.38	183.49	0.03155	0.36454	0.39609
6	12.12	5.24*	.010880	6.266	91.91	.1593	14.45	169.12	183.57	.03223	.36319	.39547
7	12.43	4.61*	.010890	6.114	91.83	.1628	14.79	168.86	183.65	.03300	.36186	.39486
8	12.75	3.96*	.010900	5.967	91.74	.1676	15.13	168.60	183.73	.03373	.36053	.39426
9	13.08	3.29*	.010910	5.822	91.66	.1717	15.46	168.34	183.80	.03445	.35921	.39366
10	13.42	2.59*	0.010920	5.682	91.58	0.1760	15.80	168.07	183.87	0.03519	0.35787	0.39306
11	13.77	1.88*	.010930	5.548	91.49	.1803	16.14	167.80	183.94	.03592	.35654	.39246
12	14.12	1.17*	.010940	5.417	91.41	.1846	16.48	167.53	184.01	.03664	.35521	.39185
13	14.48	0.44*	.010950	5.289	91.33	.1890	16.81	167.26	184.07	.03737	.35388	.39125
14	14.84	.14	.010960	5.164	91.24	.1936	17.15	166.97	184.14	.03808	.35257	.39065
15	15.21	.51	0.010971	5.042	91.16	0.1983	17.49	166.72	184.21	0.03880	0.35125	0.39005
16	15.59	.89	.010981	4.926	91.07	.2030	17.84	166.44	184.28	.03953	.34993	.38946
17	15.98	1.28	.010992	4.812	90.98	.2078	18.18	166.16	184.34	.04026	.34861	.38887
18	16.37	1.67	.011003	4.701	90.89	.2127	18.52	165.88	184.40	.04098	.34729	.38827
19	16.77	2.07	.011014	4.593	90.80	.2177	18.86	165.60	184.46	.04169	.34598	.38767

20	17.18	2.48	0.011025	4.487	90.71	0.2228	19.20	165.32	184.52	0.04241	0.34466	0.38707
21	17.60	2.90	.011036	4.386	90.62	.2280	19.55	165.03	184.58	.04313	.34335	.38648
22	18.03	3.33	.011047	4.287	90.53	.2332	19.90	164.74	184.64	.04385	.34204	.38589
23	18.46	3.76	.011058	4.190	90.44	.2387	20.24	164.45	184.69	.04457	.34073	.38530
24	18.89	4.19	.011070	4.096	90.33	.2441	20.58	164.16	184.74	.04528	.33943	.38471
25	19.34	4.64	0.011082	3.994	90.24	0.2404	20.92	163.87	184.79	0.04600	0.33812	0.38412
26	19.80	5.10	.011093	3.915	90.15	.2559	21.26	163.58	134.84	.04671	.33683	.38354
27	20.26	5.56	.011104	3.829	90.06	.2611	21.61	163.28	184.89	.04743	.33553	.38296
28	20.73	6.03	.011116	3.744	89.96	.2671	21.96	162.98	184.94	.04814	.33422	.38237
29	21.21	6.51	.011128	3.662	89.86	.2731	22.30	162.68	184.98	.04886	.33292	.38178
30	21.70	7.00	0.011140	3.581	89.76	0.2800	22.64	162.38	185.02	0.04956	0.33163	0.38119
31	22.20	7.50	.011152	3.503	89.67	.2854	22.98	162.03	185.06	.05027	.33034	.38061
32	22.71	8.01	.011164	3.437	89.58	.2909	23.33	161.77	185.10	.05099	.32904	.38003
33	23.23	8.53	.011176	3.355	89.48	.2980	23.68	161.46	185.14	.05171	.32774	.37945
34	23.75	9.05	.011188	3.283	89.39	.3046	24.03	161.15	185.18	.05242	.32645	.37887
35	24.28	9.58	0.011200	3.212	89.29	0.3113	24.38	160.84	185.22	0.05312	0.32517	0.37829
36	24.82	10.12	.011212	3.144	89.18	.3181	24.72	160.53	185.25	.05384	.32388	.37772
37	25.39	10.69	.011224	3.078	89.09	.3249	25.07	160.21	185.28	.05456	.32259	.37715
38	25.95	11.25	.011236	3.013	89.00	.3319	25.42	159.89	185.31	.05527	.32130	.37657
39	26.52	11.82	.011248	2.949	88.90	.3391	25.77	159.57	185.34	.05598	.32001	.37599
40	27.10	12.40	0.011260	2.887	88.81	0.3464	26.12	159.25	185.37	0.05668	0.31873	0.37541
41	27.69	12.99	.011272	2.827	88.71	.3538	26.47	158.93	185.40	.05738	.31745	.37483
42	28.29	13.59	.011284	2.769	88.62	.3611	26.81	158.61	185.42	.05809	.31616	.37425
43	28.90	14.20	.011296	2.712	88.52	.3687	27.16	158.23	185.44	.05879	.31489	.37368
44	29.52	14.82	.011308	2.656	88.43	.3765	27.51	157.95	185.46	.05949	.31362	.37311
45	30.15	15.45	0.011320	2.601	88.34	0.3844	27.86	157.62	185.48	0.06020	0.31234	0.37254
46	30.79	16.09	.011332	2.548	88.24	.3925	28.21	157.29	185.50	.06090	.31107	.37197
47	31.44	16.74	.011344	2.497	88.15	.4005	28.56	156.96	185.52	.06161	.30979	.37140
48	32.10	17.40	.011356	2.446	88.05	.4088	28.92	156.62	185.54	.06231	.30852	.37083
49	32.77	18.07	.011368	2.397	87.96	.4172	29.27	156.28	185.55	.06301	.30725	.37026
50	33.45	18.75	0.011380	2.348	87.87	0.4259	29.61	155.95	185.56	0.06370	0.30599	0.36969
51	34.15	19.45	.011392	2.302	87.78	.4345	29.96	155.61	185.57	.06439	.30474	.36913
52	34.86	20.16	.011404	2.256	87.67	.4433	30.31	155.27	185.58	.06509	.30348	.36857
53	35.58	20.88	.011416	2.211	87.60	.4523	30.66	154.93	185.59	.06578	.30222	.36800
54	36.31	21.61	.011428	2.167	87.51	.4615	31.00	154.59	185.59	.06646	.30097	.36743

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* Inches of mercury below one standard atmosphere (29 92 in) 14.696 lb abs.

† For Internal Latent heat see Re. Eng Vol II. No. 6 ; p 235 (Dec. 1924)

‡ Standard ton temperatures.

TABLE 2A-8. PROPERTIES OF SATURATED SULPHUR DIOXIDE (*Continued*)

(*Arranged by American Society of Refrigerating Engineers, data by David L. Fiske. Published by permission*)

Tem.	Pressure		Volume		Density		Enthalpy Above − 40°			Entropy From − 40°		
°F. *t*	Abs. lb./in.² *p*	Gage lb./in.² *gp*	Liquid ft.³/lb. *v*	Vapor ft.³/lb. *V*	Liquid lb./ft.³ *1/v*	Vapor lb./ft.³ *1/V*	Liquid Btu./lb. *h*	Latent Btu./lb. *L*	Vapor Btu./lb. *H*	Liquid Btu./lb.°F. *s*	Evap. Btu./lb.°F. *L/T*	Vapor Btu./lb.°F *S*
55	37.05	22.35	0.011440	2.124	87.41	0.4708	31.36	154.24	185.60	0.06715	0.29971	0.36686
56	37.80	23.10	.011452	2.083	87.31	.4801	31.72	153.89	185.61	.06785	.29844	.36629
57	38.56	23.86	.011464	2.043	87.22	.4894	32.08	153.54	185.62	.06854	.29719	.36573
58	39.33	24.63	.011476	2.003	87.13	.4992	32.42	153.19	185.61	.06923	.29594	.36517
59	40.12	25.42	.011488	1.964	87.04	.5092	32.76	152.84	185.60	.06992	.29469	.36461
60	40.93	26.23	0.011500	1.926	86.95	0.5194	33.10	152.49	185.59	0.07060	0.29345	0.36405
61	41.75	27.05	.011512	1.889	86.86	.5294	33.44	152.14	185.58	.07128	.29221	.36349
62	42.58	27.88	.011524	1.853	86.77	.5396	33.79	151.78	185.57	.07196	.29097	.36293
63	43.42	28.72	.011536	1.816	86.68	.5507	34.14	151.42	185.56	.07265	.28972	.36237
64	44.27	29.57	.011548	1.783	86.59	.5609	34.49	151.06	185.55	.07333	.28848	.36181
65	45.13	30.43	0.011560	1.749	86.50	0.5717	34.84	150.70	185.54	0.07401	0.28724	0.36125
66	46.00	31.30	.011572	1.716	86.41	.5827	35.19	150.34	185.53	.07469	.28601	.36070
67	46.88	32.18	.011585	1.683	86.32	.5943	35.54	149.98	185.52	.07535	.28479	.36014
68	47.78	33.08	.011598	1.652	86.22	.6054	35.88	149.62	185.50	.07602	.28356	.35958
69	48.69	33.99	.011611	1.621	86.12	.6170	36.23	149.25	185.48	.07769	.28233	.35902
70	49.62	34.92	0.011626	1.590	86.02	0.6290	36.58	148.88	185.46	0.07736	0.28110	0.35846
71	50.57	35.87	.011639	1.557	85.92	.6423	36.93	148.51	185.44	.07804	.27987	.35791
72	51.54	36.84	.011652	1.532	85.82	.6527	37.28	148.14	185.42	.07871	.27865	.35736
73	52.51	37.81	.011666	1.503	85.72	.6657	37.63	147.77	185.40	.07937	.27743	.35680
74	53.48	38.78	.011680	1.476	85.62	.6777	37.97	147.40	185.37	.08003	.27621	.35624
75	54.47	39.77	0.011693	1.448	85.52	0.6907	38.32	147.02	185.34	0.08070	0.27498	0.35568
76	55.48	40.78	.011706	1.422	85.42	.7030	38.67	146.64	185.31	.08135	.27377	.35512
77	56.51	41.81	.011719	1.396	85.33	.7163	39.01	146.26	185.27	.08201	.27255	.35456
78	57.56	42.86	.011732	1.371	85.23	.7295	39.36	145.88	185.24	.08268	.27133	.35401
79	58.62	43.92	.011746	1.343	85.13	.7446	39.71	145.50	185.21	.08336	.27012	.35346

80	59.68	44.98	0.011760	1.321	85.03	0.7570	40.05	145.12	185.17	0.08399	0.26897	0.35291
81	60.77	46.07	.011773	1.297	84.93	.7720	40.39	144.74	185.13	.08462	.26772	.35234
82	61.88	47.18	.011786	1.274	84.84	.7850	40.73	144.36	185.09	.08525	.26652	.35177
83	63.01	48.31	.011800	1.253	84.74	.7980	41.08	143.97	185.05	.08589	.26532	.35121
84	64.14	49.44	.011814	1.229	84.64	.8140	41.43	143.58	185.01	.08653	.26412	.35065
85	65.28	50.58	0.011828	1.207	84.54	0.8285	41.73	143.19	184.97	0.08718	0.26291	0.35009
86‡	66.45	51.75	.011841	1.185	84.44	.8440	42.12	142.80	184.92	.08783	.26171	.34954
87	67.64	52.94	.011854	1.164	84.35	.8590	42.46	142.41	184.87	.08847	.26052	.34899
88	68.84	54.14	.011868	1.144	84.25	.8740	42.80	142.02	184.82	.08910	.25933	.34843
89	70.04	55.34	.011882	1.124	84.15	.8998	43.15	141.62	184.77	.08974	.25813	.34787
90	71.25	56.55	0.011896	1.104	84.05	0.9058	43.50	141.22	184.72	0.09038	0.25693	0.34731
91	72.46	57.76	.011909	1.084	83.96	.9225	43.85	140.82	184.67	.09102	.25574	.34676
92	73.70	59.00	.011923	1.065	83.86	.9390	44.19	140.42	184.61	.09165	.25455	.34620
93	74.98	60.18	.011937	1.047	83.77	.9551	44.53	140.02	184.55	.09227	.25337	.34564
94	76.30	61.60	.011951	1.028	83.67	.9730	44.86	139.62	184.49	.09389	.25219	.34508
95	77.60	62.90	0.011965	1.011	83.57	0.9890	45.20	139.23	184.43	0.09349	0.25103	0.34452
96	79.03	64.33	.011979	.9931	83.47	1.007	45.54	138.83	184.37	.09411	.24986	.34397
97	80.40	65.70	.011993	.9759	83.37	1.025	45.88	138.43	184.31	.09472	.24869	.34341
98	81.77	67.07	.012008	.9591	83.27	1.043	46.22	138.03	184.25	.09532	.24753	.34285
99	83.14	68.34	.012002	.9425	83.17	1.061	46.56	137.62	184.18	.09557	.24635	.34229
100	84.52	69.82	0.012037	0.9262	83.07	1.080	46.90	137.20	184.10	0.09657	0.24516	0.34173
105	91.85	77.15	.012110	.8498	82.57	1.176	48.88	135.14	183.72	.09958	.23934	.33892
110	99.76	85.06	.012190	.7804	82.03	1.281	50.26	133.05	183.31	.10254	.23357	.33611
115	108.02	93.32	.012275	.7174	81.46	1.394	51.93	130.92	182.85	.10546	.22783	.33329
120	120.93	106.23	.012360	.6598	80.90	1.515	53.58	128.78	182.36	.10829	.22217	.33046
125	126.43	111.73	0.012445	0.6079	80.35	1.645	55.31	126.51	181.82	0.11120	0.21639	0.32759
130	136.48	121.78	.012530	.5595	79.81	1.787	56.85	124.39	181.24	.11376	.21096	.32472
135	147.21	132.51	.012620	.5158	79.23	1.947	58.47	122.15	180.62	.11640	.20542	.32182
140	158.61	143.91	.012720	.4758	78.61	2.102	60.04	119.90	179.94	.11893	.19990	.31888

‡ Standard ton temperatures.

TABLE 2A-9. PROPERTIES OF SUPERHEATED SULPHUR DIOXIDE

(Arranged by A.S.R.E. Published by permission)

Temp. °F.	Abs. Pressure 4 lb./in.² Gage Pressure 21.7 in. vac. (Sat'n Temp. — 32.60° F.)			Abs. Pressure 6 lb./in.² Gage Pressure 17.7 in. vac. (Sat'n. Temp. — 19.37° F.)			Abs. Pressure 8 lb./in.² Gage Pressure 13.6 in. vac. (Sat'n. Temp. — 3.99° F.)			Abs. Pressure 10 lb./in.² Gage Pressure 9.6 in. vac. (Sat'n. Temp. — 1.34° F.)		
t	Volume ft.³/lb. *V*	Heat Content Btu /lb. *H*	Entropy Btu./lb.°F *S*	Volume ft.³/lb. *V*	Heat Content Btu /lb. *H*	Entropy Btu /lb °F *S*	Volume ft.³/lb. *V*	Heat Content Btu /lb. *H*	Entropy Btu /lb °F *S*	Volume ft.³/lb *V*	Heat Content Btu /lb. *H*	Entropy Btu./lb.°F. *S*
(at sat'n)	*(17.30)*	*(179.57)*	*(0.42045)*	*(12.22)*	*(181.14)*	*(0.41151)*	*(9.220)*	*(182.25)*	*(0.40482)*	*(7.520)*	*(182.95)*	*(0.40000)*
−20	18.40	181.5	0.42487	......	......	......	......	......	......	......	......	......
−10	18.83	183.0	.42836	......	......	......	......	......	......	......	......	......
0	19.27	184.6	.43179	12.75	184.3	.41850	9.516	183.7	0.40871	7.545	183.2	0.40046
10	19.70	186.1	.43516	13.04	185.9	.42198	9.751	185.4	.41230	7.744	185.0	.40432
20	20.14	187.7	.43847	13.34	187.5	.42538	9.983	187.1	.41579	7.939	186.7	.40802
30	20.57	189.3	0.44161	13.63	189.1	0.42869	10.21	188.8	0.41922	8.030	188.4	0.41159
40	21.00	190.9	.44491	13.93	190.7	.43196	10.44	190.5	.42256	8.316	190.1	.41505
50	21.42	192.5	.44806	14.23	192.3	.43517	10.66	192.2	.42582	8.500	191.8	.41837
60	21.85	194.1	.45116	14.52	193.9	.43833	10.88	193.8	.42903	8.681	193.5	.42161
70	22.27	196.7	.45421	14.71	195.6	.44140	11.10	195.5	.43216	8.860	195.2	.42480
80	22.70	197.3	0.45722	15.11	197.2	0.44443	11.32	197.1	0.43524	9.038	196.9	0.42795
90	23.12	198.9	.46018	15.40	199.9	.44741	11.54	198.8	.43825	9.214	198.6	.43104
100	23.54	200.5	.46311	15.69	200.5	.45035	11.75	200.4	.44123	9.389	200.3	.43407
110	23.96	202.1	.46600	15.97	202.2	.45326	11.97	202.1	.44416	9.563	202.0	.43705
120	24.39	203.8	.46885	16.26	203.8	.45613	12.18	203.7	.44705	9.736	203.7	.43997
130	24.81	205.2	0.47167	16.54	205.3	0.45890	12.39	205.4	0.44990	9.908	205.4	0.44283
140	25.23	207.1	.47445	16.82	207.1	.46176	12.61	207.0	.45271	10.08	207.1	.44565
150	25.65	208.8	.47720	17.09	208.8	.46451	12.82	208.8	.45543	10.25	208.8	.44842
160	26.08	210.4	.47991	17.35	210.4	.46722	13.03	210.3	.45820	10.42	210.5	.45116
170	26.50	212.1	.48259	17.62	212.1	.46990	13.24	212.0	.46089	10.59	212.2	.45296
180	26.92	213.8	0.48523	17.88	213.7	0.47254	13.46	213.6	0.46353	10.76	213.8	0.45651
190	......	......	......	18.13	215.4	.47514	13.66	215.3	.46614	10.93	215.4	.45913
200	......	......	......	18.38	217.0	.47769	13.88	216.9	.46871	11.10	217.0	.46171

Temp. °F.	Abs. Pressure 15 lb./in.^{2} Gage Pressure 0.30 lb./in.^{2} (Sat'n. Temp. 14.43° F.)			Abs. Pressure 20 lb./in.^{2} Gage Pressure 5.30 lb./in.^{2} (Sat'n. Temp. 26.44° F.)			Abs. Pressure 25 lb./in.^{2} Gage Pressure 10.30 lb./in.^{2} (Sat'n. Temp. 36.33° F.)			Abs. Pressure 30 lb./in.^{2} Gage Pressure 15.30 lb./in.^{2} (Sat'n. Temp. 44.76° F.)		
(at sat'n)	*(5.110)*	*(184.17)*	*(0.39091)*	*(3.878)*	*(184.86)*	*(0.38329)*	*(3.125)*	*(185.26)*	*(0.37754)*	*(2.614)*	*(185.48)*	*(0.37269)*
20	5.192	185.4	0.39270	......	......	......	......	......	......	......	......	......
30	5.333	187.3	.39672	......	......	......	......	......	......	......	......	......
40	5.470	189.2	.40054	4.035	187.8	0.38959	3.181	186.1	0.37927	......	......	......
50	5.604	191.0	.40424	4.145	189.8	.39346	3.273	188.4	.38372	......	......	......
60	5.734	192.8	.40777	4.251	191.8	.39719	3.363	190.6	.38795	2.747	189.3	0.37969
70	5.862	195.6	0.41116	4.354	193.7	0.40080	3.451	192.7	0.39193	2.830	191.6	0.38428
80	5.988	196.4	.41443	4.454	195.6	.40429	3.536	194.7	.39582	2.907	193.8	.38848
90	6.112	198.2	.41765	4.552	197.5	.40758	3.618	196.7	.39945	2.980	195.9	.39236
100	6.233	199.9	.42076	4.648	199.3	.41093	3.696	198.6	.40291	3.052	197.9	.39603
110	6.353	201.6	.42383	4.742	201.1	.41415	3.772	200.5	.40625	3.122	199.9	.39955
120	6.471	203.3	0.42682	4.834	202.9	0.41726	3.848	202.4	0.40949	3.189	201.8	0.40293
130	6.588	205.6	.42976	4.925	204.7	.42027	3.923	204.2	.41261	3.254	203.7	.40619
140	6.705	206.7	.43264	5.015	206.5	.42322	3.998	206.0	.41563	3.318	205.6	.40935
150	6.821	208.4	.43548	5.104	208.2	.42613	4.073	207.8	.41866	3.381	207.5	.41241
160	6.937	210.1	.43825	5.193	209.9	.42898	4.145	209.6	.42156	3.443	209.3	.41539
170	7.052	211.8	0.44097	5.281	211.6	0.43176	4.216	211.4	0.42439	3.504	211.1	0.41829
180	7.167	213.5	.44366	5.369	213.3	.43449	4.287	213.2	.42717	3.565	212.9	.42112
190	7.282	215.2	.44630	5.456	215.0	.43716	4.358	215.0	.42988	3.625	214.7	.42387
200	7.396	216.9	.44889	5.542	216.7	.43977	4.428	216.7	.43253	3.685	216.5	.42657
210	......	......	......	5.629	218.4	.44234	4.498	218.4	.43413	3.744	218.3	.42921
220	......	......	......	5.715	220.1	0.44488	4.567	220.1	0.43769	3.803	220.1	0.43180
230	......	......	......	......	......	......	4.637	221.8	.44023	3.861	221.9	.43438
240	......	......	......	......	......	......	4.706	223.5	.44275	3.919	223.6	.43691
250	......	......	......	......	......	......	......	......	......	3.977	225.3	.43942
260	......	......	......	......	......	......	......	......	......	4.035	227.0	.44188

TABLE 2A-9. PROPERTIES OF SUPERHEATED SULPHUR DIOXIDE (*Continued*)

(*Arranged by A.S.R.E. Published by permission*)

Temp. °F.	Abs. Pressure 40 lb./in.² Gage Pressure 25.30 lb./in.² (Sat'n. Temp. 58.83° F.)			Abs. Pressure 50 lb./in.² Gage Pressure 35.30 lb./in.² (Sat'n. Temp. 70.40° F.)			Abs. Pressure 60 lb./in.² Gage Pressure 45.30 lb./in.² (Sat'n. Temp. 80.29° F.)			Abs. Pressure 70 lb./in.² Gage Pressure 55.30 lb./in.² (Sat'n. Temp. 88.97° F.)		
	Volume ft.³/lb.	Heat Content Btu./lb	Entropy Btu./lb.°F.	Volume ft ³/lb.	Heat Content Btu./lb.	Entropy Btu /lb.°F	Volume ft.³/lb.	Heat Content Btu./lb.	Entropy Btu./lb.°F	Volume ft.³/lb.	Heat Content Btu./lb.	Entropy Btu./lb.°F.
t	*V*	*H*	*S*	*V*	*H*	*S*	*V*	*H*	*S*	*V*	*H*	*S*
(at sat'n)	(*1.970*)	(*185.60*)	(*0.36470*)	(*1.577*)	(*185 45*)	(*0.35826*)	(*1.3144*)	(*186.16*)	(*0.35872*)	(*1.125*)	(*184.77*)	(*0.34789*)
60	1.980	185.9	0.36544	....	....	....	....	....	....	....	....	....
70	2.064	188.7	.37064	....	....	....	....	....	....	....	....	....
80	2.121	191.3	.37544	1.668	188.4	.36366	....	....	....	....	....	....
90	2.185	193.6	.37992	1.723	191.2	.36887	....	....	....	....	....	....
100	2.246	196.1	.38415	1.775	193.9	.37369	1.288	191.4	0.36403	1.181	187.6	0.35443
110	2.304	198.3	0.38810	1.825	196.4	0.37815	1.346	194.3	0.36906	1.228	191.6	0.36020
120	2.360	200.4	.39183	1.872	198.8	.38234	1.403	197.0	.37375	1.272	194.8	.36545
130	2.413	202.5	.39541	1.917	201.1	.38627	1.459	199.5	.37810	1.313	197.6	.37028
140	2.465	204.6	.39881	1.961	203.3	.38998	1.514	201.9	.38217	1.352	220.3	.37478
150	2.515	206.5	.40209	2.003	205.4	.39353	1.563	204.2	.38603	1.389	202.9	.37897
160	2.565	208.5	0.40525	2.044	207.5	0.39691	1.608	206.5	0.38963	1.424	205.3	0.38291
170	2.614	210.4	.40831	2.084	209.6	.40015	1.650	208.6	.39310	1.457	207.6	.38662
180	2.662	212.3	.41127	2.123	211.6	.40327	1.689	210.7	.39639	1.489	209.9	.39014
190	2.709	214.2	.41416	2.161	213.4	.40628	1.726	212.8	.39956	1.521	212.0	.39348
200	2.755	216.0	.41694	2.199	215.4	.40919	1.751	214.8	.40260	1.551	214.1	.39670
210	2.800	217.9	0.41966	2.237	217.3	0.41200	1.785	216.8	0.40554	1.580	216.1	0.39978
220	2.845	219.7	.42233	2.274	219.2	.41477	1.819	218.7	.40839	1.608	218.1	.40275
230	2.889	221.5	.42494	2.311	221.1	.41748	1.853	220.7	.41118	1.636	220.1	.40564
240	2.933	223.3	.42751	2.347	223.0	.42015	1.885	222.6	.41391	1.664	222.1	.40845
250	2.977	225.1	.43007	2.383	224.9	.42275	1.917	224.5	.41657	1.691	224.1	.41120
260	3.021	227.0	0.43262	2.418	226.7	0.42535	1.948	226.4	0.41917	1.718	226.0	0.41389
270	....	....	....	2.454	228.5	.42791	1.979	228.2	.42175	1.745	227.9	.41653
280	....	....	....	2.489	230.3	.43045	2.010	230.1	.42431	1.771	229.8	.41912
290	....	....	....	....	....	....	2.040	232.0	.42685	1.798	231.7	.42167
300	....	....	....	....	....	....	2.070	233.8	0.42935	1.824	233.5	0.42418

Temp. °F.	Abs. Pressure 80 lb./in.² Gage Pressure 65.30 lb./in.² (Sat'n. Temp. 96.88° F.)			Abs. Pressure 100 lb./in.² Gage Pressure 85.30 lb./in.² (Sat'n. Temp. 110.15° F.)			Abs. Pressure 120 lb./in.² Gage Pressure 105.30 lb./in.² (Sat'n. Temp. 121.52° F.)			Abs. Pressure 140 lb./in.² Gage Pressure 125.30 lb./in.² (Sat'n. Temp. 131.64° F.)		
(at sat'n)	*(0.9809)*	*(184.35)*	*(0.34357)*	*(0.7786)*	*(183.30)*	*(0.33803)*	*(0.6430)*	*(182.19)*	*(0.33954)*	*(0.5451)*	*(181.04)*	*(0.33358)*
100	0.993	185.6	0.34571	....	....	....	....	....	....	....	....	....
110	1.040	189.1	.35214	....	....	....	....	....	....	....	....	....
120	1.084	192.5	.35797	0.8190	187.3	0.34296	....	....	....	....	....	....
130	1.125	195.7	.36330	.8575	191.0	.34942	....	....	....	....	....	....
140	1.163	198.6	.36819	.8928	194.6	.35528	0.7085	190.1	0.34264	0.5734	185.1	0.33089
150	1.199	201.3	0.37270	0.9255	197.9	0.36061	0.7403	193.9	0.34904	0.6055	189.7	0.33777
160	1.232	203.9	.37692	.9561	200.9	.36558	.7700	197.4	.35484	.6345	193.6	.34442
170	1.263	206.4	.38093	.9848	203.7	.37009	.7972	200.6	.36012	.6613	196.3	.35041
180	1.292	208.7	.38461	1.012	206.4	.37431	.8228	203.7	.36494	.6861	200.8	.35588
190	1.320	211.0	.38813	1.038	209.0	.37829	.8470	206.7	.36936	.7092	204.0	.36088
200	1.347	213.3	0.39150	1.062	211.5	0.38203	0.8699	209.4	0.37348	0.7309	207.1	0.36548
210	1.374	215.5	.39471	1.086	213.8	.38556	.8916	212.0	.37737	.7513	210.0	.36976
220	1.400	217.5	.39780	1.109	216.1	.38892	.9124	214.5	.38104	.7707	212.7	.37379
230	1.426	219.6	.40079	1.131	218.4	.39214	.9324	217.0	.38451	.7892	215.4	.37758
240	1.451	221.6	.40369	1.152	220.5	.39524	.9515	219.3	.38785	.8070	217.9	.38118
250	1.476	223.6	0.40651	1.173	222.6	0.39824	0.9700	221.5	0.39106	0.8241	220.3	0.38461
260	1.500	225.6	.40926	1.194	224.7	.40114	.9880	223.7	.39416	.8405	222.6	.38789
270	1.524	227.6	.41195	1.213	226.8	.40397	1.006	225.9	.39713	.8564	224.9	.39105
280	1.547	229.5	.41459	1.232	228.8	.40673	1.023	228.0	.40002	.8720	227.1	.39408
290	1.570	231.5	.41719	1.251	230.8	.40944	1.040	230.1	.40284	.8970	229.3	.39701
300	1.593	233.4	0.41974	1.268	232.8	0.41207	1.056	233.2	0.40558	0.9017	231.5	0.39985
310	....	....	....	1.284	234.8	.41464	1.072	234.3	.40825	.9161	233.6	.40261
320	....	....	....	1.299	236.7	.41716	1.088	236.3	.41085	.9302	235.7	.40529
330	....	....	....	....	....	....	1.104	238.3	.41338	.9441	237.7	.40791
340	....	....	....	....	....	....	1.120	240.3	0.41583	0.9579	239.7	0.41049

THERMODYNAMIC PROPERTIES OF FREON GROUP OF REFRIGERANTS

(*Reprinted Courtesy of the Kinetic Chemicals Company*)

TRICHLOROMONOFLUOROMETHANE, FREON 11

TABLE 2A-10. PROPERTIES OF SATURATED VAPOR

Temp. °F. t	Pressure		Volume		Density		Enthalpy from −40°F.			Entropy from −40°F.		Temp. °F. t
	Absolute lbs./in.² p	Gage lbs./in.² $g.p.$	Liquid ft.³/lb. v_f	Vapor ft.³/lb. v_g	Liquid lbs./ft.³ $1/v_f$	Vapor lbs./ft.³ $1/v_g$	Liquid Btu./lb. h_f	Latent Btu./lb. h_{fg}	Vapor Btu./lb. h_g	Liquid Btu./lb.°F. s_f	Vapor Btu./lb.°F. s_g	
−100	0.06198	29.79	0.00948	453.1	105.5	0.002207	−11.86	92.36	80.50	−0.0304	0.2264	−100
−95	0.07904	29.76	0.00951	360.2	105.1	0.002776	−10.87	91.94	81.07	−0.0277	0.2245	−95
−90	.1000	29.72	.00954	288.6	104.8	.003467	−9.87	91.51	81.64	− .0250	.2226	−90
−85	0.1256	29.67	0.00958	232.8	104.4	0.004295	−8.88	91.09	82.21	−0.0223	0.2209	−85
−80	.1570	29.60	.00961	189.0	104.1	.005292	−7.89	90.68	82.79	− .0197	.2192	−80
−75	0.1943	29.52	0.00964	154.5	103.7	0.006473	−6.90	90.27	83.37	−0.0171	0.2176	−75
−70	.2392	29.43	.00967	127.1	103.4	.007868	−5.91	89.86	83.95	− .0146	.2160	−70
−65	0.2928	29.32	0.00971	105.1	103.0	0.009512	−4.92	89.46	84.54	−0.0121	0.2146	−65
−60	.3562	29.19	.00974	87.50	102.7	.01143	−3.94	89.06	85.12	− .0096	.2133	−60
−55	0.4308	29.04	0.00978	73.23	102.3	0.01366	−2.95	88.66	85.71	−0.0072	0.2119	−55
−50	.5184	28.86	.00981	61.58	102.0	.01624	−1.97	88.27	86.30	− .0047	.2108	−50
−45	0.6205	28.66	0.00984	52.06	101.6	0.01921	−1.00	87.88	86.89	−0.0023	0.2097	−45

–40	0.7391	28.42*	0.00988	44.21	101.25	0.02262	0.00	87.48	87.48	0.0000	0.2085	–40
–38	0.7916	28.31*	.00989	41.47	101.10	.02411	0.39	87.33	87.72	.0009	.2081	–38
–36	0.8471	28.20*	.00991	38.93	100.96	.02569	0.79	87.17	87.96	.0019	.2076	–36
–34	0.9060	28.08*	.00992	36.57	100.81	.02735	1.18	87.02	88.20	.0028	.2072	–34
–32	0.9682	27.95*	.00993	34.37	100.66	.02910	1.58	86.86	88.44	.0037	.2068	–32
–30	1.034	27.81*	0.00995	32.33	100.52	0.03093	1.97	86.70	88.67	0.0046	0.2064	–30
–28	1.103	27.67*	.00996	30.44	100.37	.03285	2.36	86.55	88.91	.0055	.2060	–28
–26	1.176	27.53*	.00998	28.68	100.22	.03487	2.75	86.40	89.15	.0064	.2057	–26
–24	1.253	27.37*	.00999	27.03	100.07	.03700	3.15	86.24	89.39	.0073	.2053	–24
–22	1.334	27.20*	.01001	25.50	99.92	.03922	3.55	86.08	89.63	.0082	.2049	–22
–20	1.420	27.03*	0.01002	24.06	99.77	0.04157	3.94	85.93	89.87	0.0091	0.2046	–20
–18	1.510	26.85*	.01004	22.72	99.63	.04401	4.33	85.78	90.11	.0100	.2043	–18
–16	1.605	26.65*	.01005	21.47	99.48	.04658	4.73	85.62	90.35	.0109	.2040	–16
–14	1.705	26.45*	.01007	20.30	99.33	.04927	5.12	85.47	90.59	.0118	.2036	–14
–12	1.810	26.24*	.01008	19.20	99.18	.05209	5.52	85.31	90.83	.0127	.2033	–12
–10	1.920	26.01*	0.01010	18.17	99.03	0.05503	5.91	85.16	91.07	0.0136	0.2030	–10
– 8	2.035	25.78*	.01011	17.21	98.87	.05810	6.31	85.00	91.31	.0145	.2027	– 8
– 6	2.156	25.53*	.01013	16.32	98.72	.06129	6.70	84.85	91.55	.0153	.2024	– 6
– 4	2.283	25.27*	.01015	15.47	98.57	.06464	7.10	84.69	91.79	.0162	.2021	– 4
– 2	2.416	25.00*	.01016	14.68	98.42	.06813	7.49	84.54	92.03	.0171	.2018	– 2

* Inches of mercury below one atmosphere.

TABLE 2A-10. PROPERTIES OF SATURATED VAPOR, FREON 11 (*Continued*)

Temp. °F. t	Pressure		Volume		Density		Enthalpy from −40°F.			Entropy from −40°F.		Temp. °F. t
	Absolute lbs./in.² p	Gage lbs./in.² $g.p.$	Liquid ft.³/lb. v_f	Vapor ft.³/lb. v_g	Liquid lbs./ft.³ $1/v_f$	Vapor lbs./ft.³ $1/v_g$	Liquid Btu./lb. h_f	Latent Btu./lb. h_{fg}	Vapor Btu./lb. h_g	Liquid Btu./lb. °F. s_f	Vapor Btu./lb. °F. s_g	
0	2.555	24.72*	0.01018	13.94	98.27	0.07176	7.89	84.38	92.27	0.0179	0.2015	0
2	2.700	24.42*	.01019	13.24	98.11	.07554	8.28	84.23	92.51	.0188	.2013	2
4	2.852	24.11*	.01021	12.58	97.96	.07949	8.68	84.07	92.75	.0197	.2010	4
5†	**2.931**	**23.95***	**.01022**	**12.27**	**97.88**	**.08152**	**8.88**	**84.00**	**92.88**	**.0201**	**.2009**	**5†**
6	3.012	23.79*	.01022	11.96	97.81	.08361	9.08	83.92	93.00	.0205	.2008	6
8	3.179	23.45*	.01024	11.38	97.65	.08790	9.48	83.76	93.24	.0213	.2005	8
10	3.352	23.10*	0.01026	10.83	97.50	0.09233	9.88	83.60	93.48	0.0222	0.2003	10
12	3.534	22.73*	.01027	10.31	97.34	.09697	10.28	83.45	93.72	.0231	.2000	12
14	3.724	22.34*	.01029	9.823	97.19	.1018	10.68	83.29	93.97	.0239	.1998	14
16	3.923	21.94*	.01031	9.359	97.03	.1068	11.07	83.14	94.21	.0248	.1996	16
18	4.129	21.52*	.01032	8.925	96.88	.1120	11.47	82.98	94.45	.0256	.1993	18
20	4.342	21.08*	0.01034	8.519	96.72	0.1174	11.87	82.82	94.69	0.0264	0.1991	20
22	4.567	20.62*	.01036	8.129	96.57	.1230	12.27	82.66	94.94	.0273	.1989	22
24	4.801	20.15*	.01037	7.760	96.41	.1289	12.68	82.50	95.18	.0281	.1987	24
26	5.043	19.66*	.01039	7.414	96.25	.1349	13.08	82.34	95.42	.0289	.1985	26
28	5.294	19.14*	.01041	7.087	96.10	.1411	13.48	82.18	95.66	.0297	.1983	28
30	5.557	18.61*	0.01042	6.776	95.94	0.1476	13.88	82.03	95.91	0.0306	0.1981	30
32	5.830	18.05*	.01044	6.481	95.78	.1543	14.28	81.87	96.15	.0314	.1979	32
34	6.115	17.47*	.01046	6.200	95.62	.1613	14.68	81.71	96.39	.0322	.1977	34
36	6.411	16.87*	.01048	5.934	95.46	.1685	15.08	81.55	96.63	.0330	.1976	36
38	6.718	16.25*	.01049	5.682	95.30	.1760	15.49	81.38	96.87	.0338	.1974	38

40	7.032	15.61*	0.01051	5.447	95.14	0.1836	15.89	81.22	97.11	0.0346	0.1972	40
42	7.362	14.94*	.01053	5.220	94.98	.1916	16.30	81.06	97.36	.0354	.1970	42
44	7.702	14.24*	.01055	5.006	94.82	.1998	16.70	80.90	97.60	.0362	.1969	44
46	8.055	13.52*	.01056	4.802	94.66	.2083	17.11	80.73	97.84	.0370	.1967	46
48	8.422	12.78*	.01058	4.607	94.50	.2170	17.52	80.57	98.08	.0378	.1966	48
50	8.804	12.00*	0.01060	4.421	94.34	0.2262	17.92	80.40	98.32	0.0386	0.1964	50
52	9.199	11.20*	.01062	4.245	94.18	.2356	18.33	80.24	98.56	.0394	.1963	52
54	9.605	10.37*	.01064	4.078	94.02	.2452	18.74	80.07	98.81	.0402	.1961	54
56	10.02	9.53*	.01066	3.921	93.85	.2550	19.15	79.90	99.05	.0410	.1960	56
58	10.45	8.65*	.01067	3.770	93.69	.2652	19.56	79.73	99.29	.0418	.1959	58
60	10.90	7.73*	0.01069	3.626	93.53	0.2758	19.96	79.57	99.53	0.0426	0.1958	60
62	11.37	6.78*	.01071	3.487	93.36	.2868	20.37	79.40	99.77	.0434	.1956	62
64	11.85	5.80*	.01073	3.356	93.20	.2980	20.78	79.23	100.01	.0442	.1955	64
66	12.35	4.78*	.01075	3.229	93.04	.3097	21.19	79.06	100.25	.0450	.1954	66
68	12.87	3.72*	.01077	3.107	92.87	.3219	21.61	78.88	100.49	.0457	.1953	68
70	13.40	2.64*	0.01079	2.993	92.71	0.3342	22.02	78.71	100.73	0.0465	0.1951	70
72	13.95	1.53*	.01081	2.883	92.54	.3469	22.43	78.54	100.97	.0473	.1950	72
74	14.51	0.39*	.01083	2.779	92.38	.3598	22.84	78.37	101.21	.0481	.1949	74
76	15.09	0.39	.01085	2.679	92.21	.3732	23.26	78.19	101.45	.0489	.1948	76
78	15.69	0.99	.01086	2.584	92.04	.3870	23.68	78.01	101.69	.0493	.1947	78

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* Inches of mercury below one atmosphere.

† Standard ton temperature.

TABLE 2A-10. PROPERTIES OF SATURATED VAPOR, FREON 11 (*Continued*)

Temp. °F. t	Pressure		Volume		Density		Enthalpy from −40°F.			Entropy from −40°F.		Temp. °F. t
	Absolute lbs./in.² p	Gage lbs./in.² $g.p.$	Liquid ft.³/lb. v_f	Vapor ft.³/lb. v_g	Liquid lbs./ft.³ $1/v_f$	Vapor lbs./ft.³ $1/v_g$	Liquid Btu/lb. h_f	Latent Btu/lb. h_{fg}	Vapor Btu/lb. h_g	Liquid Btu./lb.°F. s_f	Vapor Btu./lb.°F. s_g	
80	16.31	1.61	0.01088	2.492	91.88	0.4012	24.09	77.84	101.93	0.0504	0.1947	80
82	16.94	2.24	.01090	2.406	91.71	.4157	24.51	77.66	102.17	.0512	.1946	82
84	17.60	2.90	.01092	2.322	91.54	.4307	24.93	77.48	102.41	.0519	.1945	84
86†	18.28	3.58	.01094	2.242	91.38	.4461	25.34	77.31	102.65	.0527	.1944	86†
88	18.97	4.27	.01096	2.165	91.21	.4619	25.76	77.13	102.89	.0535	.1943	88
90	19.69	4.99	0.01098	2.091	91.04	0.4783	26.18	76.95	103.12	0.0542	0.1942	90
92	20.43	5.73	.01101	2.020	90.87	.4950	26.60	76.76	103.36	.0550	.1941	92
94	21.19	6.49	.01103	1.952	90.70	.5122	27.01	76.58	103.59	.0557	.1941	94
96	21.97	7.27	.01105	1.887	90.53	.5299	27.43	76.40	103.83	.0565	.1940	96
98	22.77	8.07	.01107	1.825	90.36	.5480	27.85	76.21	104.07	.0572	.1939	98
100	23.60	8.90	0.01109	1.765	90.19	0.5666	28.27	76.03	104.30	0.0580	0.1938	100
102	24.45	9.75	.01111	1.707	90.02	.5857	28.70	75.84	104.54	.0587	.1938	102
104	25.33	10.63	.01113	1.652	89.85	.6054	29.12	75.65	104.77	.0595	.1937	104
106	26.23	11.53	.01115	1.599	89.68	.6256	29.54	75.46	105.00	.0602	.1937	106
108	27.15	12.45	.01117	1.548	89.51	.6461	29.97	75.27	105.24	.0610	.1936	108
110	28.09	13.39	0.01119	1.499	89.34	0.6671	30.40	75.08	105.47	0.0617	0.1935	110
112	29.05	14.35	.01122	1.452	89.16	.6885	30.82	74.89	105.71	.0625	.1935	112
114	30.04	15.34	.01124	1.407	88.99	.7107	31.24	74.70	105.94	.0632	.1935	114
116	31.07	16.37	.01126	1.363	88.82	.7335	31.67	74.50	106.17	.0639	.1934	116
118	32.11	17.41	.01128	1.321	88.65	.7570	32.10	74.30	106.40	.0647	.1933	118

120	33.20	18.50	0.01130	1.281	88.47	0.7808	32.53	74.10	106.63	0.0654	0.1933	120
122	34.29	19.59	.01133	1.243	88.30	.8049	32.95	73.91	106.86	.0661	.1932	122
124	35.42	20.72	.01135	1.206	88.12	.8296	33.38	73.71	107.09	.0669	.1932	124
126	36.56	21.86	.01137	1.170	87.95	.8550	33.81	73.51	107.32	.0676	.1931	126
128	37.74	23.04	.01139	1.135	87.77	.8811	34.24	73.31	107.55	.0683	.1931	128
130	38.96	24.26	0.01142	1.101	87.60	0.9080	34.67	73.11	107.78	0.0691	0.1931	130
132	40.23	25.53	.01144	1.068	87.42	.9361	35.10	72.90	108.00	.0698	.1930	132
134	41.50	26.80	.01146	1.037	87.25	.9646	35.54	72.69	108.23	.0705	.1929	134
136	42.80	28.10	.01149	1.007	87.07	0.9927	35.97	72.49	108.46	.0712	.1929	136
138	44.12	29.42	.01151	0.9785	86.88	1.022	36.40	72.28	108.68	.0719	.1929	138
140	45.50	30.80	0.01154	0.9505	86.69	1.052	36.84	72.07	108.91	0.0727	0.1929	140
142	46.92	32.22	.01156	.9231	86.50	1.083	37.28	71.85	109.13	.0734	.1928	142
144	48.35	33.65	.01159	.8970	86.32	1.115	37.71	71.64	109.35	.0741	.1928	144
146	49.81	35.11	.01161	.8719	86.14	1.147	38.15	71.43	109.58	.0748	.1928	146
148	51.31	36.61	.01163	.8476	85.96	1.180	38.59	71.21	109.80	.0755	.1927	148
150	52.85	38.15	0.01166	0.8240	85.78	1.214	39.02	71.00	110.02	0.0763	0.1927	150
152	54.41	39.71	.01168	.8014	85.60	1.248	39.46	70.78	110.24	.0770	.1927	152
154	56.01	41.31	.01171	.7794	85.41	1.283	39.91	70.56	110.47	.0777	.1927	154
156	57.65	42.95	.01173	.7581	85.23	1.319	40.35	70.34	110.69	.0784	.1927	156
158	59.32	44.62	.01176	.7376	85.04	1.356	40.79	70.12	110.90	.0791	.1926	158
160	61.04	46.34	0.01179	0.7176	84.85	1.394	41.23	69.89	111.12	0.0798	0.1926	160

† Standard ton temperature.

TABLE 2A-11. PROPERTIES OF SUPERHEATED VAPOR, FREON 11

Temp. °F.	Abs. Pressure 0 08 lbs./in.² Gage Pressure 29 76 ins. vac. (Sat'n. Temp. −94.8°F.)			Abs. Pressure 0.10 lbs./in.² Gage Pressure 29.72 ins. vac. (Sat'n. Temp. −90.0°F.)			Abs. Pressure 0.12 lbs./in.² Gage Pressure 29.68 ins. vac. (Sat'n. Temp. −86.1°F.)			Abs. Pressure 0.14 lbs./in.² Gage Pressure 29.64 ins. vac. (Sat'n. Temp. −82.7°F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(at sat'n)	(356.1)	(81.10)	(0.2244)	(288.6)	(81.64)	(0.2226)	(243.0)	(82.09)	(0.2213)	(210.1)	(82.48)	(0.2201)
− 90	360.8	81.64	0.2259	....	....	....	....	....	....	....	....	....
− 80	370.5	82.80	.2290	296.4	82.80	0.2257	247.0	82.79	0.2231	211.7	82.79	0.2209
− 70	380.3	83.96	.2320	304.2	83.96	.2287	253.5	83.96	.2261	217.2	83.96	.2239
− 60	390.1	85.14	.2350	312.0	85.14	.2317	260.0	85.14	.2291	222.8	85.14	.2269
− 50	399.8	86.33	0.2379	319.8	86.33	0.2346	266.5	86.32	0.2320	228.4	86.32	0.2298
− 40	409.6	87.52	.2408	327.7	87.52	.2375	273.0	87.52	.2349	234.0	87.52	.2327
− 30	419.4	88.73	.2436	335.5	88.73	.2403	279.5	88.73	.2377	239.6	88.73	.2355
− 20	429.1	89.95	.2464	343.3	89.95	.2431	286.1	89.95	.2405	245.2	89.95	.2383
− 10	438.9	91.18	.2491	351.1	91.18	.2459	292.6	91.18	.2433	250.8	91.17	.2410
0	448.7	92.42	0.2518	358.9	92.41	0.2486	299.1	92.41	0.2460	256.3	92.41	0.2437
10	458.4	93.67	.2545	366.7	93.66	.2513	305.6	93.66	.2487	261.9	93.66	.2464
20	468.2	94.92	.2572	374.6	94.92	.2539	312.1	94.92	.2513	267.5	94.92	.2491
30	478.0	96.19	.2598	382.4	96.19	.2565	318.6	96.19	.2539	273.1	96.19	.2517
40	487.8	97.47	.2624	390.2	97.47	.2591	325.1	97.47	.2565	278.7	97.47	.2543
50	497.5	98.76	0.2650	398.0	98.76	0.2617	331.7	98.76	0.2591	284.3	98.76	0.2569
60	507.3	100.07	.2675	405.8	100.06	.2642	338.2	100.06	.2616	289.8	100.06	.2594
70	517.1	101.38	.2700	413.6	101.38	.2667	344.7	101.38	.2641	295.4	101.37	.2619
80	526.8	102.70	.2725	421.4	102.70	.2692	351.2	102.70	.2666	301.0	102.70	.2644
90	536.6	104.03	.2749	429.3	104.03	.2717	357.7	104.03	.2690	306.6	104.03	.2668
100	546.4	105.37	0.2773	437.1	105.37	0.2741	364.2	105.37	0.2714	312.2	105.37	0.2692
110	556.1	106.73	.2797	444.9	106.73	.2765	370.7	106.72	.2738	317.8	106.72	.2716
120	565.9	108.09	.2821	452.7	108.09	.2789	377.2	108.09	.2762	323.3	108.09	.2740
130	575.7	109.46	.2845	460.5	109.46	.2812	383.8	109.46	.2786	328.9	109.46	.2764
140	585.4	110.85	.2868	468.3	110.85	.2835	390.3	110.84	.2809	334.5	110.84	.2787
150	595.2	112.24	0.2891	476.1	112.24	0.2858	396.8	112.24	0.2832	340.1	112.24	0.2810
160	605.0	113.65	.2914	484.0	113.64	.2881	403.3	113.64	.2855	345.7	113.64	.2833
170	614.7	115.06	.2937	491.8	115.06	.2904	409.8	115.06	.2878	351.3	115.06	.2856
180	624.5	116.49	.2959	499.6	116.49	.2927	416.3	116.49	.2900	356.8	116.48	.2878
190	634.3	117.92	.2981	507.4	117.92	.2949	422.8	117.92	.2922	362.4	117.92	.2900
200	644.0	119.37	0.3003	515.2	119.37	0.2971	429.3	119.37	0.2944	368.0	119.37	0.2922
210	653.8	120.83	.3025	523.0	120.83	.2993	435.8	120.82	.2966	373.6	120.82	.2944
220	....	....	....	530.9	122.29	.3015	442.4	122.29	.2988	379.2	122.29	.2966

Temp. °F.	Abs. Pressure 0.16 lbs./in.² Gage Pressure 29.59 ins. vac. (Sat'n. Temp. −79.6°F.)			Abs. Pressure 0.18 lbs./in.² Gage Pressure 29.55 ins. vac. (Sat'n. Temp. −76.9°F.)			Abs. Pressure 0.20 lbs./in.² Gage Pressure 29.51 ins. vac. (Sat'n. Temp. −74.4°F.)			Abs. Pressure 0.22 lbs./in.² Gage Pressure 29.47 ins. vac. (Sat'n. Temp. −72.1°F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(at sat'n)	(185.4)	(82.84)	(0.2191)	(165.9)	(83.15)	(0.2182)	(150.3)	(83.44)	(0.2174)	(137.4)	(83.70)	(0.2167)
− 70	190.1	83.96	0.2219	168.9	83.96	0.2202	152.0	83.95	0.2187	138.2	83.95	0.2173
− 60	195.0	85.13	.2249	173.3	85.13	.2232	155.9	85.13	.2217	141.7	85.13	.2203
− 50	199.8	86.32	0.2278	177.6	86.32	0.2261	159.9	86.32	0.2246	145.3	86.32	0.2232
− 40	204.7	87.52	.2307	182.0	87.52	.2290	163.8	87.52	.2275	148.9	87.52	.2261
− 30	209.6	88.73	.2335	186.3	88.73	.2318	167.7	88.72	.2303	152.4	88.72	.2289
− 20	214.5	89.94	.2363	190.7	89.94	.2346	171.6	89.94	.2331	156.0	89.94	.2317
− 10	219.4	91.17	.2391	195.0	91.17	.2374	175.5	91.17	.2359	159.5	91.17	.2345
0	224.3	92.41	0.2418	199.4	92.41	0.2401	179.4	92.41	0.2386	163.1	92.41	0.2372
10	229.2	93.66	.2445	203.7	93.66	.2428	183.3	93.66	.2413	166.6	93.66	.2399
20	234.1	94.92	.2471	208.0	94.92	.2454	187.2	94.92	.2439	170.2	94.92	.2425
30	238.9	96.19	.2497	212.4	96.19	.2480	191.1	96.19	.2465	173.7	96.19	.2451
40	243.8	97.47	.2523	216.7	97.47	.2506	195.0	97.47	.2491	177.3	97.47	.2477
50	248.7	98.76	0.2549	221.1	98.76	0.2532	199.0	98.76	0.2517	180.9	98.76	0.2503
60	253.6	100.06	.2574	225.4	100.06	.2557	202.9	100.06	.2542	184.4	100.06	.2528
70	258.5	101.37	.2599	229.8	101.37	.2582	206.8	101.37	.2567	188.0	101.37	.2553
80	263.4	102.69	.2624	234.1	102.69	.2607	210.7	102.69	.2592	191.5	102.69	.2578
90	268.3	104.03	.2649	238.4	104.03	.2632	214.6	104.03	.2617	195.1	104.02	.2603
100	273.1	105.37	0.2673	242.8	105.37	0.2656	218.5	105.37	0.2641	198.6	105.37	0.2627
110	278.0	106.72	.2697	247.1	106.72	.2680	222.4	106.72	.2665	202.2	106.72	.2651
120	282.9	108.08	.2721	251.5	108.08	.2704	226.3	108.08	.2689	205.7	108.08	.2675
130	287.8	109.46	.2744	255.8	109.46	.2727	230.2	109.46	.2712	209.3	109.46	.2698
140	292.7	110.84	.2767	260.2	110.84	.2750	234.1	110.84	.2735	212.8	110.84	.2721
150	297.6	112.24	0.2790	264.5	112.24	0.2773	238.0	112.24	0.2758	216.4	112.23	0.2744
160	302.5	113.64	.2813	268.8	113.64	.2796	241.9	113.64	.2781	219.9	113.64	.2767
170	307.3	115.06	.2836	273.2	115.06	.2819	245.9	115.06	.2804	223.5	115.06	.2790
180	312.2	116.48	.2859	277.5	116.48	.2842	249.8	116.48	.2827	227.1	116.48	.2813
190	317.1	117.92	.2881	281.9	117.92	.2864	253.7	117.92	.2849	230.6	117.92	.2835
200	322.0	119.37	0.2903	286.2	119.37	0.2886	257.6	119.36	0.2871	234.2	119.36	0.2857
210	326.9	120.82	.2925	290.5	120.82	.2908	261.5	120.82	.2893	237.7	120.82	.2879
220	331.8	122.29	.2947	294.9	122.29	.2930	265.4	122.29	.2915	241.3	122.29	.2901
230	336.6	123.77	.2969	299.2	123.77	.2952	269.3	123.77	.2937	244.8	123.77	.2923

TABLE 2A-11. PROPERTIES OF SUPERHEATED VAPOR, FREON 11 (*Continued*)

Temp. °F.	Abs. Pressure 0.24 lbs./in.² Gage Pressure 29.43 ins. vac. (Sat'n. Temp. −69.9°F.)			Abs. Pressure 0.26 lbs./in.² Gage Pressure 29.39 ins. vac. (Sat'n. Temp. −68.1°F.)			Abs. Pressure 0.28 lbs./in.² Gage Pressure 29.35 ins. vac. (Sat'n. Temp. −66.2°F.)			Abs. Pressure 0.30 lbs./in.² Gage Pressure 29.31 ins. vac. (Sat'n. Temp. −64.4°F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(at sat'n)	(126.7)	(83.96)	(0.2160)	(117.5)	(84.18)	(0.2155)	(109.6)	(84.40)	(0.2149)	(102.8)	(84.61)	(0.2145)
− 60	129.9	85.13	0.2191	119.9	85.13	0.2179	111.3	85.13	0.2168	103.9	85.12	0.2158
− 50	133.2	86.32	0.2220	122.9	86.32	0.2208	114.1	86.31	0.2197	106.5	86.31	0.2187
− 40	136.4	87.51	.2249	125.9	87.51	.2237	116.9	87.51	.2226	109.1	87.51	.2216
− 30	139.7	88.72	.2277	128.9	88.72	.2265	119.7	88.72	.2254	111.7	88.72	.2244
− 20	143.0	89.94	.2305	132.0	89.94	.2293	122.5	89.94	.2282	114.3	89.94	.2272
− 10	146.2	91.17	.2332	135.0	91.17	.2321	125.3	91.17	.2310	117.0	91.16	.2300
0	149.5	92.41	0.2359	138.0	92.41	0.2348	128.1	92.40	0.2337	119.6	92.40	0.2327
10	152.7	93.66	.2386	141.0	93.65	.2375	130.9	93.65	.2364	122.2	93.65	.2354
20	156.0	94.92	.2413	144.0	94.91	.2401	133.7	94.91	.2390	124.8	94.91	.2380
30	159.3	96.19	.2439	147.0	96.18	.2427	136.5	96.18	.2416	127.4	96.18	.2406
40	162.5	97.47	.2465	150.0	97.46	.2453	139.3	97.46	.2442	130.0	97.46	.2432
50	165.8	98.76	0.2491	153.0	98.76	0.2479	142.1	98.75	0.2468	132.6	98.75	0.2458
60	169.0	100.06	.2516	156.0	100.06	.2504	144.9	100.06	.2493	135.2	100.05	.2483
70	172.3	101.37	.2541	159.0	101.37	.2529	147.7	101.37	.2518	137.8	101.37	.2508
80	175.6	102.69	.2566	162.0	102.69	.2554	150.5	102.69	.2543	140.4	102.69	.2533
90	178.8	104.02	.2590	165.0	104.02	.2579	153.3	104.02	.2568	143.0	104.02	.2558
100	182.1	105.37	0.2614	168.1	105.36	0.2603	156.0	105.36	0.2592	145.6	105.36	0.2582
110	185.3	106.72	.2638	171.1	106.72	.2627	158.8	106.72	.2616	148.2	106.72	.2606
120	188.6	108.08	.2662	174.1	108.08	.2651	161.6	108.08	.2640	150.8	108.08	.2630
130	191.8	109.46	.2686	177.1	109.46	.2674	164.4	109.45	.2663	153.5	109.45	.2653
140	195.1	110.84	.2709	180.1	110.84	.2697	167.2	110.84	.2686	156.1	110.84	.2676
150	198.4	112.23	0.2732	183.1	112.23	0.2720	170.0	112.23	0.2709	158.7	112.23	0.2699
160	201.6	113.64	.2755	186.1	113.64	.2743	172.8	113.64	.2732	161.3	113.64	.2722
170	204.9	115.05	.2778	189.1	115.05	.2766	175.6	115.05	.2755	163.9	115.05	.2745
180	208.1	116.48	.2800	192.1	116.48	.2789	178.4	116.48	.2778	166.5	116.48	.2768
190	211.4	117.92	.2822	195.1	117.92	.2811	181.2	117.92	.2800	169.1	117.91	.2790
200	214.6	119.36	0.2844	198.1	119.36	0.2833	184.0	119.36	0.2822	171.7	119.36	0.2812
210	217.9	120.82	.2866	201.1	120.82	.2855	186.8	120.82	.2844	174.3	120.82	.2834
220	221.2	122.29	.2888	204.1	122.29	.2877	189.6	122.29	.2866	176.9	122.29	.2856
230	224.4	123.77	.2910	207.1	123.76	.2899	192.3	123.76	.2898	179.5	123.76	.2878
240	227.7	125.25	.2931	210.2	125.25	.2920	195.1	125.25	.2909	182.1	125.25	.2899

Temp °F.	Abs. Pressure 0.32 lbs /in.^{2} Gage Pressure 29.27 ins. vac. (Sat'n. Temp. −62.9°F.)			Abs. Pressure 0.34 lbs./in.^{2} Gage Pressure 29.23 ins. vac. (Sat'n. Temp. −61.3°F.)			Abs. Pressure 0.36 lbs./in.^{2} Gage Pressure 29.19 ins. vac. (Sat'n. Temp. −59.7°F.)			Abs. Pressure 0.38 lbs./in.^{2} Gage Pressure 29.15 ins. vac. (Sat'n. Temp. −58.4°F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(at sat'n)	(96.70)	(84.79)	(0.2140)	(91.37)	(84.97)	(0 2136)	(86.63)	(85.15)	(0.2132)	(82.33)	(85.31)	(0.2129)
— 60	97.41	85.12	0.2149	91.67	85.12	0.2140	....	....	....	....	....	....
— 50	99.85	86.31	0.2178	93.97	86.31	0.2169	88.74	86.31	0.2161	84.07	86.31	0.2153
— 40	102.3	87.51	.2207	96.27	87.51	.2198	90.92	87.51	.2190	86.13	87.50	.2182
— 30	104.7	88.72	.2235	98.58	88.71	.2226	93.09	88.71	.2218	88.19	88.71	.2210
— 20	107.2	89.93	.2263	100.9	89.93	.2254	95.27	89.93	.2246	90.25	89.93	.2238
— 10	109.6	91.16	.2291	103.2	91.16	.2282	97.44	91.16	.2274	92.31	91.16	.2266
0	112.1	92.40	0.2318	105.5	92.40	0.2309	99.62	92.40	0.2301	94.37	92.40	0.2293
10	114.5	93.65	.2345	107.8	93.65	.2336	101.8	93.65	.2328	96.43	93.65	.2320
20	117.0	94.91	.2371	110.1	94.91	.2362	104.0	94.91	.2354	98.49	94.91	.2346
30	119.4	96.18	.2397	112.4	96.18	.2388	106.1	96.18	.2380	100.5	96.18	.2372
40	121.9	97.46	.2423	114.7	97.46	.2414	108.3	97.46	.2406	102.6	97.46	.2398
50	124.3	98.75	0.2449	117.0	98.75	0.2440	110.5	98.75	0.2432	104.7	98.75	0.2424
60	126.8	100.05	.2474	119.3	100.05	.2465	112.7	100.05	.2457	106.7	100.05	.2449
70	129.2	101.37	.2499	121.6	101.36	.2490	114.8	101.36	.2482	108.8	101.36	.2474
80	131.6	102.69	.2524	123.9	102.69	.2515	117.0	102.68	.2507	110.8	102.68	.2499
90	134.1	104.02	.2549	126.2	104.02	.2540	119.2	104.02	.2531	112.9	104.02	.2524
100	136.5	105.36	0.2573	128.5	105.36	0.2564	121.3	105.36	0.2555	115.0	105.36	0.2548
110	139.0	106.72	.2597	130.8	106.71	.2588	123.5	106.71	.2579	117.0	106.71	.2572
120	141.4	108.08	.2621	133.1	108.08	.2612	125.7	108.08	.2603	119.1	108.08	.2596
130	143.9	109.45	.2644	135.4	109.45	.2635	127.9	109.45	.2627	121.1	109.45	.2619
140	146.3	110.84	.2667	137.7	110.84	.2658	130.0	110.83	.2650	123.2	110.83	.2642
150	148.7	112.23	0.2590	140.0	112.23	0.2681	132.2	112.23	0.2673	125.2	112.23	0.2665
160	151.2	113.64	.2713	142.3	113.63	.2704	134.4	113.63	.2696	127.3	113.63	.2688
170	153.6	115.05	.2736	144.6	115.05	.2727	136.6	115.05	.2719	129.4	115.05	.2711
180	156.1	116.48	.2759	146.9	116.48	.2750	138.7	116.48	.2741	131.4	116.48	.2734
190	158.5	117.91	.2781	149.2	117.91	.2772	140.9	117.91	.2763	133.5	117.91	.2756
200	161.0	119.36	0.2803	151.5	119.36	0.2794	143.1	119.36	0.2785	135.5	119.36	0.2778
210	163.4	120.82	.2825	153.8	120.82	.2816	145.2	120.82	.2807	137.6	120.81	.2800
220	165.8	122.28	.2847	156.1	122.28	.2838	147.4	122.28	.2829	139.7	122.28	.2822
230	168.3	123.76	.2869	158.4	123.76	.2860	149.6	123.76	.2851	141.7	123.76	.2843
240	170.7	125.25	.2890	160.7	125.25	.2881	151.8	125.25	.2872	143.8	125.25	.2864
250	....	....	....	....	....	....	153.9	126.75	0.2893	145.8	126.75	0.2885

TABLE 2A-11. PROPERTIES OF SUPERHEATED VAPOR, FREON 11 (*Continued*)

Temp. °F.	Abs. Pressure 0.40 lbs. /in.^{2} Gage Pressure 29.11 ins. vac. (Sat'n. Temp. -57.1°F.)			Abs. Pressure 0.42 lbs./in.^{2} Gage Pressure 29.07 ins. vac. (Sat'n. Temp. -55.7°F.)			Abs. Pressure 0.44 lbs./in.^{2} Gage Pressure 29.02 ins. vac. (Sat'n. Temp. -54.5°F.)			Abs. Pressure 0.46 lbs./in.^{2} Gage Pressure 28.98 ins. vac. (Sat'n. Temp. -53.3°F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(at sat'n)	(78.47)	(85.47)	(0.2125)	(74.98)	(85.62)	(0.2121)	(71.78)	(85.77)	(0.2118)	(68.86)	(85.91)	(0.2115)
— 50	79.86	86.31	0.2146	76.05	86.31	0.2139	72.58	86.30	0.2132	69.42	86.30	0.2125
— 40	81.81	87.50	.2174	77.91	87.50	.2167	74.36	87.50	.2161	71.12	87.50	.2154
— 30	83.77	88.71	.2202	78.78	88.71	.2195	76.14	88.71	.2189	72.83	88.71	.2182
— 20	85.73	89.93	.2230	81.64	89.93	.2223	77.92	89.93	.2217	74.53	89.93	.2210
— 10	87.69	91.16	.2258	83.50	91.16	.2251	79.70	91.16	.2245	76.23	91.15	.2238
0	89.64	92.40	0.2285	85.37	92.40	0.2278	81.48	92.39	0.2272	77.94	92.39	0.2265
10	91.60	93.65	.2312	87.23	93.65	.2305	83.26	93.64	.2299	79.64	93.64	.2292
20	93.56	94.91	.2339	89.10	94.90	.2332	85.04	94.90	.2325	81.34	94.90	.2318
30	95.51	96.18	.2365	90.96	96.18	.2358	86.82	96.17	.2351	83.04	96.17	.2344
40	97.47	97.46	.2391	92.82	97.46	.2384	88.60	97.45	.2377	84.74	97.45	.2370
50	99.43	98.75	0.2417	94.69	98.75	0.2410	90.38	98.75	0.2403	86.44	98.74	0.2396
60	101.4	100.05	.2442	96.55	100.05	.2435	92.16	100.05	.2428	88.15	100.05	.2421
70	103.3	101.36	.2467	98.41	101.36	.2460	93.93	101.36	.2453	89.85	101.36	.2446
80	105.3	102.68	.2492	100.3	102.68	.2485	95.71	102.68	.2478	91.55	102.68	.2471
90	107.3	104.02	.2516	102.1	104.01	.2509	97.49	104.01	.2503	93.25	104.01	.2496
100	109.2	105.36	0.2540	104.0	105.36	0.2533	99.27	105.36	0.2527	94.95	105.36	0.2520
110	111.2	106.71	.2564	105.9	106.71	.2557	101.0	106.71	.2551	96.65	106.71	.2544
120	113.1	108.07	.2588	107.7	108.07	.2581	102.8	108.07	.2575	98.35	108.07	.2568
130	115.1	109.45	.2612	109.6	109.45	.2605	104.6	109.45	.2598	100.1	109.45	.2592
140	117.0	110.83	.2635	111.5	110.83	.2628	106.4	110.83	.2621	101.8	110.83	.2615
150	119.0	112.23	0.2658	113.3	112.23	0.2651	108.2	112.23	0.2644	103.5	112.22	0.2638
160	120.9	113.63	.2681	115.2	113.63	.2674	109.9	113.63	.2667	105.2	113.63	.2661
170	122.9	115.05	.2704	117.0	115.05	.2697	111.7	115.05	.2690	106.9	115.05	.2684
180	124.8	116.47	.2726	118.9	116.47	.2719	113.5	116.47	.2712	108.6	116.47	.2706
190	126.8	117.91	.2748	120.8	117.91	.2741	115.3	117.91	.2734	110.3	117.91	.2728
200	128.8	119.36	0.2770	122.6	119.36	0.2763	117.0	119.36	0.2756	112.0	119.35	0.2750
210	130.7	120.81	.2792	124.5	120.81	.2785	118.8	120.81	.2778	113.7	120.81	.2772
220	132.7	122.28	.2814	126.3	122.28	.2807	120.6	122.28	.2800	115.4	122.28	.2794
230	134.6	123.76	.2836	128.2	123.76	.2829	122.4	123.76	.2822	117.1	123.76	.2816
240	136.6	125.25	.2857	130.1	125.25	.2850	124.2	125.25	.2843	118.8	125.25	.2837
250	138.5	126.75	0.2878	131.9	126.75	0.2871	125.9	126.75	0.2864	120.5	126.75	0.2858

Temp. °F.	Abs. Pressure 0.48 lbs./in.^{2} Gage Pressure 28.94 ins. vac. (Sat'n. Temp. −52.2°F.)			Abs. Pressure 0.50 lbs./in.^{2} Gage Pressure 28.90 ins vac. (Sat'n. Temp. −51.1°F.)			Abs. Pressure 0.52 lbs./in.^{2} Gage Pressure 28.86 ins. vac. (Sat'n. Temp. −49.9°F.)			Abs. Pressure 0.54 lbs./in.^{2} Gage Pressure 28.82 ins. vac. (Sat'n. Temp. −48.9°F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(at sat'n)	(66.24)	(86.04)	(0.2113)	(63.68)	(86.18)	(0.2110)	(61.41)	(86.31)	(0.2108)	(59.28)	(86.42)	(0.2106)
−50	66.52	86.30	0.2119	63.86	86.30	0.2113	....	....	....	....	....	....
−40	68.16	87.50	.2148	65.42	87.50	.2142	62.90	87.49	0.2136	60.57	87.49	0.2131
−30	69.79	88.71	.2176	66.99	88.70	.2170	64.41	88.70	.2164	62.02	88.70	.2159
−20	71.42	89.92	.2204	68.56	89.92	.2198	65.92	89.92	.2192	63.47	89.92	.2187
−10	73.05	91.15	.2232	70.12	91.15	.2226	67.42	91.15	.2220	64.92	91.15	.2215
0	74.68	92.39	0.2259	71.69	92.39	0.2253	68.93	92.39	0.2247	66.37	92.39	0.2242
10	76.31	93.64	.2286	73.26	93.64	.2280	70.44	93.64	.2274	67.82	93.64	.2269
20	77.95	94.90	.2312	74.82	94.90	.2306	71.94	94.90	.2301	69.27	94.90	.2295
30	79.58	96.17	.2338	76.39	96.17	.2332	73.45	96.17	.2327	70.72	96.17	.2321
40	81.21	97.45	.2364	77.96	97.45	.2358	74.95	97.45	.2353	72.17	97.45	.2347
50	82.84	98.74	0.2390	79.52	98.74	0.2384	76.46	98.74	0.2379	73.62	98.74	0.2373
60	84.47	100.05	.2415	81.09	100.04	.2409	77.96	100.04	.2404	75.07	100.04	.2398
70	86.10	101.36	.2440	82.65	101.36	.2434	79.47	101.36	.2429	76.52	101.35	.2423
80	87.73	102.68	.2465	84.22	102.68	.2459	80.97	102.68	.2454	77.97	102.68	.2448
90	89.36	104.01	.2490	85.78	104.01	.2484	82.48	104.01	.2478	79.42	104.01	.2473
100	90.99	105.35	0.2514	87.35	105.35	0.2508	83.99	105.35	0.2502	80.87	105.35	0.2497
110	92.62	106.71	.2538	88.91	106.71	.2532	85.49	106.71	.2526	82.32	106.70	.2521
120	94.25	108.07	.2562	90.48	108.07	.2556	86.99	108.07	.2550	83.77	108.07	.2545
130	95.88	109.45	.2585	92.04	109.44	.2579	88.50	109.44	.2574	85.22	109.44	.2568
140	97.51	110.83	.2608	93.61	110.83	.2602	90.00	110.83	.2597	86.67	110.83	.2591
150	99.14	112.22	0.2631	95.17	112.22	0.2625	91.51	112.22	0.2620	88.12	112.22	0.2614
160	100.8	113.63	.2654	96.74	113.63	.2648	93.01	113.63	.2643	89.57	113.63	.2637
170	102.4	115.04	.2677	98.30	115.04	.2671	94.52	115.04	.2666	91.02	115.04	.2660
180	104.0	116.47	.2700	99.87	116.47	.2694	96.02	116.47	.2688	92.46	116.47	.2683
190	105.7	117.91	.2722	101.4	117.91	.2716	97.53	117.91	.2710	93.91	117.91	.2705
200	107.3	119.35	0.2744	103.0	119.35	0.2738	99.03	119.35	0.2732	95.36	119.35	0.2727
210	108.9	120.81	.2766	104.6	120.81	.2760	100.5	120.81	.2754	96.81	120.81	.2749
220	110.5	122.28	.2788	106.1	122.28	.2782	102.0	122.28	.2776	98.26	122.28	.2771
230	112.2	123.76	.2810	107.7	123.76	.2804	103.5	123.76	.2798	99.71	123.75	.2793
240	113.8	125.25	.2831	109.3	125.24	.2825	105.0	125.24	.2819	101.2	125.24	.2814
250	115.4	126.74	0.2852	110.8	126.74	0.2846	106.6	126.74	0.2840	102.6	126.74	0.2835
260	....	....	....	....	....	....	108.1	128.25	.2861	104.1	128.25	.2856

TABLE 2A-11. PROPERTIES OF SUPERHEATED VAPOR, FREON 11 (*Continued*)

Temp. °F.	Abs. Pressure 0.56 lbs./in.² Gage Pressure 28.78 ins. vac. (Sat'n. Temp. −48.0°F.)			Abs. Pressure 0.58 lbs./in.² Gage Pressure 28.74 ins. vac. (Sat'n. Temp. −47.0°F.)			Abs. Pressure 0.60 lbs./in.² Gage Pressure 28.70 ins. vac. (Sat'n. Temp. −46.0°F.)			Abs. Pressure 0.62 lbs./in.² Gage Pressure 28.66 ins. vac. (Sat'n. Temp. −45.0°F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(at sat'n)	(57.28)	(86.54)	(0.2104)	(55.43)	(86.66)	(0.2101)	(53.71)	(86.77)	(0.2099)	(52.10)	(86.89)	(0.2097)
− 40	58.40	87.49	0.2126	56.38	87.49	0.2121	54.50	87.49	0.2116	52.74	87.49	0.2111
− 30	59.80	88.70	.2154	57.73	88.70	.2149	55.80	88.70	.2144	54.00	88.70	.2139
− 20	61.20	89.92	.2182	59.08	89.92	.2177	57.11	89.92	.2172	55.26	89.92	.2167
− 10	62.60	91.15	.2210	60.44	91.15	.2205	58.42	91.15	.2200	56.53	91.14	.2195
0	64.00	92.39	0.2237	61.79	92.39	0.2232	59.72	92.38	0.2227	57.79	92.38	0.2222
10	65.40	93.64	.2264	63.14	93.64	.2259	61.03	93.63	.2254	59.06	93.63	.2249
20	66.79	94.90	.2290	64.49	94.90	.2285	62.33	94.89	.2280	60.32	94.89	.2275
30	68.19	96.17	.2316	65.84	96.17	.2311	63.64	96.17	.2306	61.58	96.16	.2301
40	69.59	97.45	.2342	67.19	97.45	.2337	64.95	97.45	.2332	62.85	97.44	.2327
50	70.99	98.74	0.2368	68.54	98.74	0.2363	66.25	98.74	0.2358	64.11	98.74	0.2353
60	72.39	100.04	.2393	69.89	100.04	.2388	67.56	100.04	.2383	65.37	100.04	.2378
70	73.79	101.35	.2418	71.24	101.35	.2413	68.86	101.35	.2408	66.64	101.35	.2403
80	75.18	102.67	.2443	72.59	102.67	.2438	70.17	102.67	.2433	67.90	102.67	.2428
90	76.58	104.01	.2468	73.94	104.01	.2462	71.47	104.01	.2458	69.16	104.01	.2453
100	77.98	105.35	0.2492	75.29	105.35	0.2486	72.78	105.35	0.2482	70.43	105.35	0.2477
110	79.38	106.70	.2516	76.64	106.70	.2510	74.08	106.70	.2506	71.69	106.70	.2501
120	80.78	108.07	.2540	77.99	108.07	.2534	75.38	108.07	.2530	72.95	108.06	.2525
130	82.17	109.44	.2563	79.34	109.44	.2558	76.69	109.44	.2553	74.21	109.44	.2548
140	83.57	110.83	.2586	80.69	110.83	.2581	77.99	110.82	.2576	75.48	110.82	.2571
150	84.97	112.22	0.2609	82.04	112.22	0.2604	79.30	112.22	0.2599	76.74	112.22	0.2594
160	86.37	113.63	.2632	83.38	113.62	.2627	80.60	113.62	.2622	78.00	113.62	.2617
170	87.76	115.04	.2655	84.73	115.04	.2650	81.91	115.04	.2645	79.26	115.04	.2640
180	89.16	116.47	.2677	86.08	116.47	.2672	83.21	116.47	.2668	80.52	116.47	.2663
190	90.56	117.90	.2699	87.43	117.90	.2694	84.51	117.90	.2690	81.79	117.90	.2685
200	91.95	119.35	0.2721	88.78	119.35	0.2716	85.82	119.35	0.2712	83.05	119.35	0.2707
210	93.35	120.81	.2743	90.13	120.81	.2738	87.12	120.81	.2734	84.31	120.81	.2729
220	94.75	122.28	.2765	91.48	122.28	.2760	88.43	122.27	.2756	85.57	122.27	.2751
230	96.14	123.75	.2787	92.83	123.75	.2782	89.73	123.75	.2777	86.83	123.75	.2773
240	97.54	125.24	.2808	94.18	125.24	.2803	91.03	125.24	.2798	88.10	125.24	.2794
250	98.94	126.74	0.2829	95.52	126.74	0.2824	92.34	126.74	0.2819	89.36	126.74	0.2815
260	100.3	128.25	.2850	96.87	128.25	.2845	93.64	128.25	.2840	90.62	128.25	.2836

Temp. °F.	Abs. Pressure 0.64 lbs./in.² Gage Pressure 28.62 ins. vac. (Sat'n. Temp. −44.2°F.)			Abs. Pressure 0.66 lbs./in.² Gage Pressure 28.58 ins. vac. (Sat'n. Temp. −43.3°F.)			Abs. Pressure 0.68 lbs./in.² Gage Pressure 28.54 ins. vac. (Sat'n. Temp. −42.5°F.)			Abs. Pressure 0.70 lbs./in.² Gage Pressure 28.50 ins. vac. (Sat'n. Temp. −41.7°F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(at sat'n)	(50.57)	(86.99)	(0.2095)	(49.14)	(87.09)	(0.2093)	(47.78)	(87.19)	(0.2091)	(46.50)	(87.29)	(0.2089)
− 40	51.08	87.49	0.2106	49.53	87.49	0.2102	48.07	87.48	0.2097	46.69	87.48	0.2093
− 30	52.31	88.69	.2134	50.72	88.69	.2130	49.22	88.69	.2125	47.81	88.69	.2121
− 20	53.53	89.91	.2162	51.91	89.91	.2158	50.38	89.91	.2153	48.93	89.91	.2149
− 10	54.76	91.14	.2190	53.09	91.14	.2186	51.53	91.14	.2181	50.05	91.14	.2177
0	55.98	92.38	0.2217	54.28	92.38	0.2213	52.68	92.38	0.2208	51.17	92.38	0.2204
10	57.21	93.63	.2244	55.47	93.63	.2240	53.84	93.63	.2235	52.29	93.63	.2231
20	58.43	94.89	.2270	56.66	94.89	.2266	54.99	94.89	.2262	53.41	94.89	.2258
30	59.66	96.16	.2296	57.85	96.16	.2292	56.14	96.16	.2288	54.53	96.16	.2284
40	60.88	97.44	.2322	59.03	97.44	.2318	57.29	97.44	.2314	55.65	97.44	.2310
50	62.10	98.74	0.2348	60.22	98.73	0.2344	58.45	98.73	0.2340	56.77	98.73	0.2336
60	63.33	100.04	.2373	61.41	100.04	.2369	59.60	100.03	.2365	57.89	100.03	.2361
70	64.55	101.35	.2398	62.59	101.35	.2394	60.75	101.35	.2390	59.01	101.35	.2386
80	65.78	102.67	.2423	63.78	102.67	.2419	61.90	102.67	.2415	60.13	102.67	.2411
90	67.00	104.00	.2448	64.97	104.00	.2444	63.05	104.00	.2439	61.25	104.00	.2435
100	68.22	105.35	0.2472	66.15	105.35	0.2468	64.20	105.34	0.2463	62.37	105.34	0.2459
110	69.45	106.70	.2496	67.34	106.70	.2492	65.36	106.70	.2487	63.49	106.70	.2483
120	70.67	108.06	.2520	68.52	108.06	.2516	66.51	108.06	.2511	64.60	108.06	.2507
130	71.89	109.44	.2544	69.71	109.44	.2539	67.66	109.44	.2535	65.72	109.44	.2531
140	73.11	110.82	.2567	70.90	110.82	.2562	68.81	110.82	.2558	66.84	110.82	.2554
150	74.34	112.22	0.2590	72.08	112.22	0.2585	69.96	112.22	0.2581	67.96	112.21	0.2577
160	75.56	113.62	.2613	73.27	113.62	.2608	71.11	113.62	.2604	69.08	113.62	.2600
170	76.78	115.04	.2636	74.45	115.04	.2631	72.26	115.04	.2627	70.20	115.04	.2623
180	78.01	116.46	.2658	75.64	116.46	.2654	73.41	116.46	.2649	71.31	116.46	.2645
190	79.23	117.90	.2680	76.83	117.90	.2676	74.56	117.90	.2671	72.43	117.90	.2667
200	80.45	119.35	0.2702	78.01	119.35	0.2698	75.71	119.35	0.2693	73.55	119.35	0.2689
210	81.67	120.80	.2724	79.20	120.80	.2720	76.87	120.80	.2715	74.67	120.80	.2711
220	82.90	122.27	.2746	80.38	122.27	.2742	78.02	122.27	.2737	75.79	122.27	.2733
230	84.12	123.75	.2768	81.57	123.75	.2764	79.17	123.75	.2759	76.90	123.75	.2755
240	85.34	125.24	.2789	82.75	125.24	.2785	80.32	125.24	.2780	78.02	125.24	.2776
250	86.56	126.74	0.2810	83.94	126.74	0.2806	81.47	126.74	0.2801	79.14	126.74	0.2797
260	87.79	128.25	.2831	85.12	128.25	.2827	82.62	128.25	.2822	80.26	128.25	.2818

TABLE 2A-11. PROPERTIES OF SUPERHEATED VAPOR, FREON 11 (*Continued*)

Temp. °F.	Abs. Pressure 0.72 lbs./in.^{2} Gage Pressure 28.45 ins. vac. (Sat'n. Temp. −40.8°F.)			Abs. Pressure 0.74 lbs./in.^{2} Gage Pressure 28.41 ins. vac. (Sat'n. Temp. −40.0°F.)			Abs. Pressure 0.76 lbs./in.^{2} Gage Pressure 28.37 ins. vac. (Sat'n. Temp. −39.2°F.)			Abs. Pressure 0.78 lbs./in.^{2} Gage Pressure 28.33 ins. vac. (Sat'n. Temp. −38.4°F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(at sat'n)	(45.30)	(87.38)	(0.2087)	(44.16)	(87.48)	(0.2085)	(43.08)	(87.58)	(0.2083)	(42.05)	(87.67)	(0.2082)
− 40	45.39	87.48	0.2089	....	....	....	....	....	....	....	....	....
− 30	46.48	88.69	.2117	45.22	88.69	0.2113	44.03	88.69	0.2109	42.90	88.69	0.2106
− 20	47.57	89.91	.2145	46.28	89.91	.2141	45.06	89.91	.2137	43.90	89.90	.2134
− 10	48.66	91.14	.2173	47.34	91.14	.2169	46.09	91.14	.2165	44.91	91.13	.2162
0	49.75	92.38	0.2200	48.40	92.38	0.2196	47.12	92.38	0.2192	45.91	92.37	0.2189
10	50.84	93.63	.2227	49.46	93.63	.2223	48.16	93.63	.2219	46.92	93.62	.2216
20	51.93	94.89	.2253	50.52	94.89	.2249	49.19	94.89	.2246	47.92	94.88	.2242
30	53.02	96.16	.2279	51.58	96.16	.2275	50.22	96.16	.2272	48.93	96.15	.2268
40	54.10	97.44	.2305	52.64	97.44	.2301	51.25	97.44	.2298	49.94	97.44	.2294
50	55.19	98.73	0.2331	53.70	98.73	0.2327	52.28	98.73	0.2324	50.94	98.73	0.2320
60	56.28	100.03	.2356	54.76	100.03	.2352	53.31	100.03	.2349	51.94	100.03	.2345
70	57.37	101.35	.2381	55.82	101.34	.2377	54.34	101.34	.2374	52.95	101.34	.2370
80	58.46	102.67	.2406	56.88	102.67	.2402	55.38	102.66	.2399	53.95	102.66	.2395
90	59.55	104.00	.2431	57.93	104.00	.2427	56.41	104.00	.2423	54.96	104.00	.2420
100	60.63	105.34	0.2455	58.99	105.34	0.2451	57.44	105.34	0.2447	55.96	105.34	0.2444
110	61.72	106.70	.2479	60.05	106.70	.2475	58.47	106.69	.2471	56.97	106.69	.2468
120	62.81	108.06	.2503	61.11	108.06	.2499	59.50	108.06	.2495	57.97	108.06	.2492
130	63.89	109.43	.2527	62.17	109.43	.2523	60.53	109.43	.2519	58.97	109.43	.2515
140	64.98	110.82	.2550	63.22	110.82	.2546	61.56	110.82	.2542	59.98	110.82	.2538
150	66.07	112.21	0.2573	64.28	112.21	0.2569	62.59	112.21	0.2565	60.98	112.21	0.2561
160	67.16	113.62	.2596	65.34	113.63	.2592	63.62	113.62	.2588	61.99	113.62	.2584
170	68.24	115.04	.2619	66.40	115.03	.2615	64.65	115.03	.2611	62.99	115.03	.2607
180	69.33	116.46	.2641	67.46	116.46	.2637	65.68	116.46	.2633	63.99	116.46	.2630
190	70.42	117.90	.2663	68.51	117.90	.2659	66.71	117.90	.2655	65.00	117.90	.2652
200	71.51	119.34	0.2685	69.57	119.34	0.2681	67.74	119.34	0.2677	66.00	119.34	0.2674
210	72.60	120.80	.2707	70.63	120.80	.2703	68.77	120.80	.2699	67.00	120.80	.2696
220	73.68	122.27	.2729	71.69	122.27	.2725	69.80	122.27	.2721	68.01	122.27	.2718
230	74.77	123.75	.2751	72.74	123.75	.2747	70.83	123.75	.2743	69.01	123.75	.2739
240	75.85	125.24	.2772	73.80	125.24	.2768	71.86	125.24	.2764	70.01	125.23	.2760
250	76.94	127.74	0.2793	74.86	126.74	0.2789	72.89	126.73	0.2785	71.02	126.73	0.2781
260	78.03	128.25	.2814	75.92	128.24	.2810	73.92	128.24	.2806	72.02	128.24	.2802
270	....	....	....	76.97	129.76	.2831	74.95	129.76	.2827	73.02	129.76	.2823

Temp. °F.	Abs. Pressure 0.80 lbs./in.² Gage Pressure 28.29 ins. vac. (Sat'n. Temp. -37.7°F.)		
t	V	H	S
(at sat'n)	(41.06)	(87.76)	(0.2080)
— 30	41.82	88.69	0.2102
— 20	42.80	89.90	.2130
— 10	43.78	91.13	.2158
0	44.76	92.37	0.2185
10	45.74	93.62	.2212
20	46.72	94.88	.2238
30	47.70	96.15	.2264
40	48.68	97.43	.2290
50	49.66	98.73	0.2316
60	50.64	100.03	.2341
70	51.62	101.34	.2366
80	52.60	102.66	.2391
90	53.58	104.00	.2416
100	54.56	105.34	0.2440
110	55.54	106.69	.2464
120	56.52	108.06	.2488
130	57.50	109.43	.2511
140	58.48	110.82	.2534
150	59.46	112.21	0.2557
160	60.43	113.62	.2580
170	61.41	115.03	.2603
180	62.39	116.46	.2626
190	63.37	117.90	.2648
200	64.35	119.34	0.2670
210	65.33	120.80	.2692
220	66.31	122.27	.2714
230	67.28	123.75	.2736
240	68.26	125.23	.2757
250	69.24	126.73	0.2778
260	70.22	128.24	.2799
270	71.20	129.77	.2820

Temp. °F.	Abs. Pressure 0.9 lb./in² Gage Pressure 28.09 in. Vac. (Sat'n. Temp. —34.2°F.)			Abs. Pressure 1.0 lb./in.² Gage Pressure 27.88 in. Vac. (Sat'n. Temp. —31.0°F.)		
t	V	H	S	V	H	S
(at sat'n)	(36.81)	(88.18)	(0.2073)	(33.37)	(88.55)	(0.2066)
—40	.....	......	.....	.....	......	.....
—30	37.16	86.68	0.2085	33.43	88.67	0.2069
—20	38.03	89.90	.2113	34.22	89.90	.2097
—10	38.90	91.13	.2141	35.00	91.13	.2125
0	39.78	92.37	0.2168	35.79	92.36	0.2153
10	40.65	93.62	.2195	36.57	93.61	.2180
20	41.52	94.88	.2221	37.36	94.87	.2206
30	42.39	96.15	.2247	38.14	96.14	.2232
40	43.26	97.43	.2273	38.93	97.42	.2258
50	44.14	98.72	0.2299	39.71	98.71	0.2284
60	45.01	100.02	.2324	40.50	100.02	.2309
70	45.88	101.33	.2349	41.28	101.33	.2334
80	46.75	102.66	.2374	42.07	102.66	.2359
90	47.62	103.99	.2398	42.85	103.99	.2383
100	48.49	105.33	0.2423	43.63	105.33	0.2407
110	49.36	106.68	.2447	44.42	106.68	.2431
120	50.23	108.05	.2470	45.20	108.05	.2455
130	51.10	109.43	.2494	45.98	109.42	.2478
140	51.97	110.81	.2517	46.77	110.80	.2502
150	52.84	112.21	0.2540	47.55	112.20	0.2525
160	53.71	113.61	.2563	48.33	113.60	.2548
170	54.58	115.03	.2586	49.12	115.02	.2571
180	55.45	116.46	.2608	49.90	116.45	.2593
190	56.32	117.89	.2631	50.68	117.89	.2615
200	57.19	119.34	0.2653	51.47	119.34	0.2637
210	58.06	120.80	.2675	52.25	120.80	.2659
220	58.93	122.26	.2696	53.03	122.26	.2681
230	59.80	123.74	.2718	53.82	123.74	.2703
240	60.67	125.23	.2739	54.60	125.23	.2724
250	61.54	126.73	0.2761	55.38	126.73	0.2745
260	62.41	128.24	.2782	56.16	128.24	.2766
270	63.28	129.76	0.2803	56.95	129.76	0.2787

TABLE 2A-11. PROPERTIES OF SUPERHEATED VAPOR, FREON 11 (*Continued*)

Temp. °F.	Abs. Pressure 1.1 lb./in.² Gage Pressure 27.68 in. Vac. (Sat'n. Temp. —28.1°F.)			Abs. Pressure 1.2 lb./in.² Gage Pressure 27.48 in. Vac. (Sat'n. Temp. —25.4°F.)			Abs. Pressure 1.3 lb./in.² Gage Pressure 27.27 in. Vac. (Sat'n. Temp. —22.8°F.)			Abs. Pressure 1.4 lb./in.² Gage Pressure 27.07 in. Vac. (Sat'n. Temp. —20.5°F.)		
(at sat'n)	(30.52)	(88.90)	(0 2061)	(28.15)	(89.23)	(0.2056)	(26.13)	(89.53)	(0.2051)	(24.39)	(89.81)	(0.2047)
—20	31.09	89.89	0.2084	28.49	89.88	0.2071	26.29	89.88	0.2060	24.41	89.87	0.2049
—10	31.81	91.12	.2111	29.15	91.11	.2099	26.90	91.11	.2087	24.97	91.10	.2076
0	32.52	92.35	0.2139	29.80	92.35	0.2126	27.50	92.34	0.2114	25.53	92.34	0.2104
10	33.24	93.60	.2166	30.46	93.60	.2153	28.11	93.59	.2141	26.09	93.59	.2131
20	33.95	94.87	.2192	31.11	94.86	.2179	28.71	94.86	.2168	26.65	94.85	.2157
30	34.66	96.14	.2218	31.77	96.13	.2205	29.32	96.13	.2194	27.21	96.12	.2183
40	35.38	97.42	.2244	32.42	97.41	.2231	29.92	97.41	.2220	27.78	97.40	.2209
50	36.09	98.71	0.2270	33.08	98.70	0.2257	30.52	98.70	0.2246	28.34	98.69	0.2235
60	36.81	100.01	.2295	33.73	100.01	.2282	31.13	100.00	.2271	28.90	100.00	.2260
70	37.52	101.32	.2320	34.39	101.32	.2307	31.73	101.31	.2296	29.46	101.31	.2285
80	38.23	102.65	.2345	35.04	102.65	.2332	32.34	102.64	.2321	30.02	102.64	.2310
90	38.95	103.98	.2369	35.69	103.98	.2357	32.94	103.97	.2345	30.58	103.97	.2334
100	39.66	105.32	0.2393	36.35	105.32	0.2381	33.54	105.32	0.2369	31.14	105.31	0.2358
110	40.37	106.68	.2417	37.00	106.67	.2405	34.15	106.67	.2393	31.70	106.66	.2382
120	41.08	108.05	.2441	37.65	108.04	.2429	34.75	108.04	.2417	32.26	108.03	.2406
130	41.80	109.42	.2465	38.31	109.41	.2452	35.35	109.41	.2440	32.82	109.40	.2430
140	42.51	110.80	.2488	38.96	110.79	.2475	35.96	110.79	.2464	33.38	110.79	.2453
150	43.22	112.20	0.2511	39.61	112.19	0.2498	36.56	112.19	0.2487	33.94	112.19	0.2476
160	43.93	113.60	.2534	40.27	113.60	.2521	37.16	113.59	.2510	34.51	113.59	.2499
170	44.65	115.02	.2557	40.92	115.02	.2544	37.77	115.01	.2532	35.07	115.01	.2522
180	45.36	116.45	.2579	41.57	116.45	.2567	38.37	116.44	.2555	35.63	116.44	.2544
190	46.07	117.88	.2602	42.23	117.88	.2589	38.97	117.87	.2577	36.19	117.87	.2567
200	46.78	119.33	0.2624	42.88	119.33	0.2611	39.58	119.32	0.2599	36.75	119.32	0.2589
210	47.50	120.79	.2646	43.53	120.79	.2633	40.18	120.78	.2621	37.31	120.78	.2611
220	48.21	122.25	.2667	44.19	122.25	.2655	40.78	122.25	.2643	37.87	122.24	.2632
230	48.92	123.73	.2689	44.84	123.73	.2676	41.39	123.73	.2665	38.43	123.72	.2654
240	49.63	125.22	.2710	45.49	125.22	.2698	41.99	125.22	.2686	38.99	125.21	.2675
250	50.34	126.72	0.2731	46.14	126.72	0.2719	42.59	126.72	0.2707	39.55	126.71	0.2697
260	51.06	128.24	.2753	46.80	128.23	.2740	43.19	128.23	.2728	40.11	128.23	.2718
270	51.77	129.76	.2774	47.45	129.75	.2761	43.80	129.75	.2749	40.67	129.75	.2739
280	52.48	131.29	0.2794	48.10	131.28	0.2782	44.40	131.28	0.2770	41.23	131.28	0.2760

Temp. °F.	Abs. Pressure 1.6 lb./in.² Gage Pressure 26.66 in. Vac. (Sat'n. Temp.-16.1°F.)			Abs. Pressure 1.8 lb./in.² Gage Pressure 26.26 in. Vac. (Sat'n. Temp.-12.2°F.)			Abs. Pressure 2.0 lb./in.² Gage Pressure 25.85 in. Vac. (Sat'n. Temp.-8.6°F.)			Abs. Pressure 2.2 lb./in.² Gage Pressure 25.44 in. Vac. (Sat'n. Temp.-5.3°F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(at sat'n)	(21.53)	(90.34)	(0.2040)	(19.30)	(90.81)	(0.2033)	(17.50)	(91.24)	(0.2028)	(16.02)	(91.63)	(0.2023)
—10	21.83	91.09	0.2057	19.39	91.08	0.2040	.....	......	.....	.....	......	.....
0	22.32	92.33	0.2084	19.83	92.32	0.2067	17.83	92.31	0.2052	16.20	92.29	0.2038
10	22.82	93.58	.2111	20.27	93.57	.2094	18.23	93.56	.2079	16.56	93.54	.2065
20	23.31	94.84	.2138	20.71	94.83	.2120	18.62	94.82	.2105	16.92	94.81	.2091
30	23.80	96.11	.2164	21.14	96.10	.2147	19.02	96.09	.2131	17.28	96.08	.2117
40	24.29	97.39	.2190	21.58	97.38	.2173	19.41	97.37	.2157	17.64	97.36	.2143
50	24.78	98.68	0.2215	22.02	98.67	0.2198	19.81	98.66	0.2183	17.99	98.65	0.2169
60	25.27	99.99	.2241	22.46	99.98	.2223	20.20	99.97	.2208	18.35	99.96	.2194
70	25.77	101.30	.2266	22.89	101.29	.2248	20.59	101.28	.2233	18.71	101.27	.2219
80	26.26	102.63	.2290	23.33	102.62	.2273	20.99	102.61	.2258	19.07	102.60	.2244
90	26.75	103.96	.2315	23.77	103.95	.2298	21.38	103.94	.2282	19.43	103.93	.2269
100	27.24	105.30	0.2339	24.20	105.29	0.2322	21.77	105.28	0.2307	19.79	105.27	0.2293
110	27.73	106.65	.2363	24.64	106.65	.2346	22.17	106.64	.2331	20.14	106.63	.2317
120	28.22	108.02	.2387	25.08	108.02	.2370	22.56	108.01	.2354	20.50	108.00	.2340
130	28.71	109.40	.2410	25.51	109.39	.2393	22.95	109.38	.2378	20.86	109.37	.2364
140	29.20	110.78	.2434	25.95	110.77	.2417	23.35	110.76	.2401	21.22	110.75	.2387
150	29.69	112.18	0.2457	26.39	112.17	0.2440	23.74	112.17	0.2424	21.57	112.16	0.2410
160	30.18	113.58	.2480	26.82	113.57	.2463	24.13	113.57	.2447	21.93	113.56	.2433
170	30.67	115.00	.2502	27.26	114.99	.2485	24.52	114.98	.2470	22.29	114.98	.2456
180	31.16	116.43	.2525	27.69	116.42	.2508	24.92	116.41	.2492	22.65	116.41	.2479
190	31.66	117.86	.2547	28.13	117.86	.2530	25.31	117.85	.2515	23.00	117.84	.2501
200	32.15	119.31	0.2569	28.57	119.31	0.2552	25.70	119.30	0.2537	23.36	119.29	0.2523
210	32.64	120.77	.2591	29.00	120.77	.2574	26.10	120.76	.2559	23.72	120.75	.2545
220	33.13	122.24	.2613	29.44	122.23	.2596	26.49	122.22	.2581	24.07	122.22	.2567
230	33.62	123.72	.2634	29.87	123.71	.2617	26.88	123.70	.2602	24.43	123.70	.2588
240	34.11	125.21	.2656	30.31	125.20	.2639	27.27	125.19	.2624	24.79	125.19	.2610
250	34.60	126.71	0.2677	30.75	126.70	0.2660	27.66	126.69	0.2645	25.15	126.69	0.2631
260	35.09	128.22	.2698	31.18	128.21	.2681	28.06	128.21	.2666	25.50	128.20	.2652
270	35.58	129.74	.2719	31.62	129.73	.2702	28.45	129.73	.2687	25.86	129.72	.2673
280	36.07	131.27	.2740	32.05	131.26	.2723	28.84	131.26	.2708	26.21	131.25	.2694
290	36.56	132.81	0.2761	32.49	132.81	0.2744	29.23	132.80	.2728	26.57	132.79	.2715
300	.....	......	.....	.....	......	.....	29.62	134.35	0.2749	26.93	134.35	0.2735

TABLE 2A-11. PROPERTIES OF SUPERHEATED VAPOR, FREON 11 (*Continued*)

Temp. °F.	Abs. Pressure 2.4 lb./in.^{2} Gage Pressure 25.04 in. Vac. (Sat'n. Temp. -2.2°F.)			Abs. Pressure 2.6 lb./in.^{2} Gage Pressure 24.63 in. Vac. (Sat'n. Temp. + 0.6°F.)			Abs. Pressure 2.8 lb./in.^{2} Gage Pressure 24.22 in. Vac. (Sat'n. Temp 3.3°F.)			Abs. Pressure 3.0 lb./in.^{2} Gage Pressure 23.81 in. Vac. (Sat'n Temp. 5.9°F.)		
(at sat'n)	(14.77)	(92.00)	(0.2018)	(13.71)	(92.34)	(0.2015)	(12.81)	(92.67)	(0.2011)	(12.01)	(92.98)	(0.2008)
0	14.84	92.28	0.2025	.....	.....	.....	.....	.....	.....	.....	.....	.....
10	15.17	93.53	.2052	13.99	93.52	0.2040	12.99	93.51	0.2029	12.11	93.50	0.2019
20	15.50	94.80	.2078	14.30	94.78	.2067	13.27	94.77	.2056	12.38	94.76	.2046
30	15.83	96.07	.2105	14.60	96.06	.2093	13.55	96.05	.2082	12.64	96.04	.2072
40	16.16	97.35	.2131	14.91	97.34	.2119	13.84	97.33	.2108	12.91	97.32	.2098
50	16.49	98.64	0.2156	15.21	98.63	0.2144	14.12	98.62	0.2134	13.17	98.61	0.2123
60	16.82	99.95	.2181	15.52	99.94	.2170	14.40	99.93	.2159	13.43	99.92	.2149
70	17.14	101.26	.2206	15.82	101.25	.2195	14.68	101.24	.2184	13.70	101.23	.2174
80	17.47	102.59	.2231	16.12	102.58	.2220	14.96	102.57	.2209	13.96	102.56	.2199
90	17.80	103.92	.2256	16.43	103.91	.2244	15.25	103.90	.2233	14.22	103.90	.2223
100	18.13	105.27	0.2280	16.73	105.26	0.2268	15.53	105.25	0.2258	14.49	105.24	0.2247
110	18.46	106.63	.2304	17.03	106.62	.2292	15.81	106.61	.2282	14.75	106.60	.2271
120	18.79	108.00	.2328	17.34	107.99	.2316	16.09	107.98	.2305	15.01	107.97	.2295
130	19.11	109.37	.2351	17.64	109.36	.2340	16.37	109.35	.2329	15.28	109.34	.2319
140	19.44	110.75	.2375	17.94	110.74	.2363	16.65	110.73	.2352	15.54	110.72	.2342
150	19.77	112.15	0.2398	18.24	112.14	0.2386	16.94	112.13	0.2375	15.80	112.12	0.2365
160	20.10	113.55	.2421	18.55	113.54	.2409	17.22	113.54	.2398	16.06	113.53	.2388
170	20.43	114.97	.2443	18.85	114.96	.2432	17.50	114.95	.2421	16.33	114.95	.2411
180	20.75	116.40	.2466	19.15	116.39	.2454	17.78	116.38	.2444	16.59	116.38	.2433
190	21.08	117.83	.2488	19.45	117.83	.2477	18.06	117.82	.2466	16.85	117.81	.2456
200	21.41	119.28	0.2510	19.76	119.28	0.2499	18.34	119.27	0.2488	17.11	119.26	0.2478
210	21.74	120.74	.2532	20.06	120.74	.2521	18.62	120.73	.2510	17.38	120.72	.2500
220	22.06	122.21	.2554	20.36	122.20	.2542	18.90	122.19	.2532	17.64	122.19	.2522
230	22.39	123.69	.2576	20.66	123.68	.2564	19.18	123.67	.2553	17.90	123.67	.2543
240	22.72	125.18	.2597	20.97	125.17	.2585	19.47	125.17	.2575	18.16	125.16	.2565
250	23.05	126.68	0.2618	21.27	126.67	0.2607	19.75	126.67	0.2596	18.43	126.66	0.2586
260	23.37	128.19	.2639	21.57	128.19	.2628	20.03	128.18	.2617	18.69	128.17	.2607
270	23.70	129.71	.2660	21.87	129.71	.2649	20.31	129.70	.2638	18.95	129.70	.2628
280	24.03	131.25	.2681	22.18	131.24	.2670	20.59	131.23	.2659	19.21	131.23	.2649
290	24.35	132.79	.2702	22.48	132.78	.2690	20.87	132.77	.2680	19.47	132.77	.2670
300	24.68	134.34	0.2723	22.78	134.33	0.2711	21.15	134.33	0.2700	19.74	134.32	0.2690
310	.....	.....	.....	23.08	135.89	0.2731	21.43	135.89	0.2721	20.00	135.88	0.2711

Temp. °F.	Abs. Pressure 3.5 lb./in.² Gage Pressure 22.80 in. Vac. (Sat'n. Temp. 11.6°F.)			Abs. Pressure 4.0 lb./in.² Gage Pressure 21.78 in. Vac. (Sat'n. Temp. 16.7°F.)			Abs. Pressure 4.5 lb./in.² Gage Pressure 20.76 in. Vac. (Sat'n. Temp. 21.4°F.)			Abs. Pressure 5.0 lb./in.² Gage Pressure 19.74 in. Vac. (Sat'n. Temp. 25.6°F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(at sat'n)	(10.41)	(93.67)	(0.2001)	(9.194)	(94.30)	(0.1995)	(8.243)	(94.87)	(0.1990)	(7.475)	(95.38)	(0.1985)
20	10.60	94.74	0.2023	9.256	94.71	0.2003	.....	.....	.....	.....	.....	.....
30	10.82	96.01	.2049	9.455	95.99	.2030	8.393	95.96	0.2012	7.543	95.94	0.1997
40	11.05	97.29	.2075	9.655	97.27	.2056	8.570	97.24	.2038	7.703	97.22	.2023
50	11.28	98.59	0.2101	9.853	98.56	0.2081	8.747	98.54	0.2064	7.863	98.51	0.2048
60	11.50	99.89	.2126	10.05	99.87	.2107	8.924	99.84	.2089	8.023	99.82	.2074
70	11.73	101.21	.2151	10.25	101.18	.2132	9.101	101.16	.2114	8.182	101.14	.2099
80	11.95	102.54	.2176	10.45	102.51	.2157	9.278	102.49	.2139	8.341	102.47	.2124
90	12.18	103.87	.2201	10.65	103.45	.2181	9.454	103.83	.2164	8.500	103.80	.2148
100	12.41	105.22	0.2225	10.84	105.20	0.2205	9.631	105.18	0.2188	8.659	105.16	0.2173
110	12.63	106.58	.2249	11.04	106.56	.2229	9.807	106.54	.2212	8.818	106.51	.2197
120	12.86	107.95	.2273	11.24	107.93	.2253	9.983	107.91	.2236	8.977	107.88	.2220
130	13.08	109.32	.2296	11.44	109.30	.2277	10.16	109.28	.2260	9.135	109.26	.2244
140	13.31	110.70	.2320	11.64	110.68	.2300	10.34	110.66	.2283	9.294	110.65	.2267
150	13.53	112.10	0.2343	11.83	112.08	0.2323	10.51	112.06	0.2306	9.452	112.05	0.2290
160	13.76	113.51	.2366	12.03	113.49	.2346	10.69	113.47	.2329	9.610	113.45	.2313
170	13.98	114.93	.2388	12.23	114.91	.2369	10.86	114.89	.2352	9.769	114.87	.2336
180	14.21	116.36	.2411	12.43	116.34	.2391	11.04	116.32	.2374	9.927	116.30	.2359
190	14.44	117.79	.2433	12.62	117.77	.2414	11.21	117.76	.2396	10.09	117.74	.2381
200	14.66	119.24	0.2455	12.82	119.22	0.2436	11.39	119.21	0.2419	10.25	119.19	0.2403
210	14.89	120.70	.2477	13.02	120.68	.2458	11.56	120.67	.2441	10.40	120.65	.2425
220	15.11	122.17	.2499	13.22	122.15	.2480	11.74	122.13	.2462	10.56	122.12	.2447
230	15.34	123.65	.2521	13.41	123.63	.2501	11.92	123.61	.2484	10.72	123.60	.2469
240	15.56	125.14	.2542	13.61	125.13	.2523	12.09	125.11	.2506	10.88	125.09	.2490
250	15.79	126.64	0.2563	13.81	126.63	0.2544	12.27	126.61	0.2527	11.04	126.59	0.2511
260	16.01	128.16	.2585	14.00	128.14	.2565	12.44	128.12	.2548	11.19	128.11	.2533
270	16.24	129.68	.2606	14.20	129.66	.2586	12.62	129.65	.2569	11.35	129.63	.2554
280	16.46	131.21	.2626	14.40	131.20	.2607	12.79	131.18	.2590	11.51	131.16	.2574
290	16.69	132.76	.2647	14.59	132.74	.2628	12.97	132.73	.2611	11.67	132.71	.2595
300	16.91	134.31	0.2668	14.79	134.30	0.2648	13.14	134.28	0.2631	11.82	134.27	0.2616
310	17.13	135.87	.2688	14.99	135.86	.2669	13.32	135.84	.2652	11.98	135.83	.2636
320	17.36	137.44	0.2708	15.18	137.43	0.2689	13.49	137.41	.2672	12.14	137.40	.2656
330	.....	.....	.....	.....	.....	.....	13.67	138.99	0.2692	12.30	138.98	0.2677

TABLE 2A-11. PROPERTIES OF SUPERHEATED VAPOR, FREON 11 (*Continued*)

Temp. °F.	Abs. Pressure 5.5 lb./in.² Gage Pressure 18.73 in. Vac. (Sat'n. Temp. 29.6°F.)			Abs. Pressure 6.0 lb./in.² Gage Pressure 17.71 in. Vac. Sat'n. Temp. 33.2°F.)			Abs. Pressure 6.5 lb./in.² Gage Pressure 16.69 in. Vac. (Sat'n. Temp. 36.6°F.)			Abs. Pressure 7.0 lb./in.² Gage Pressure 15.67 in. Vac. (Sat'n. Temp. 39.8°F.)		
(at sat'n)	(6.842)	(95 86)	(0.1982)	(6.313)	(96.29)	(0.1978)	(5.861)	(96.70)	(0.1975)	(5.470)	(97.09)	(0.1972)
30	6.847	95.91	0.1983	.....	.....	.....	.....	.....	.....	.....	.....	.....
40	6.993	97.19	.2009	6.401	97.16	0.1996	5.901	97.14	0.1984	5.472	97.11	0.1973
50	7.138	98.49	0.2034	6.534	98.46	0.2021	6.024	98.44	0.2009	5.587	98.41	0.1998
60	7.283	99.80	.2060	6.668	99.77	.2047	6.148	99.75	.2035	5.702	99.72	.2024
70	7.428	101.11	.2085	6.802	101.09	.2072	6.271	101.07	.2060	5.817	101.04	.2049
80	7.573	102.44	.2110	6.936	102.42	.2097	6.395	102.40	.2085	5.932	102.37	.2074
90	7.718	103.78	.2134	7.069	103.76	.2121	6.518	103.73	.2110	6.046	103.71	.2099
100	7.863	105.13	0.2159	7.202	105.11	0.2146	6.641	105.08	0.2134	6.161	105.06	0.2123
110	8.008	106.49	.2183	7.335	106.47	.2170	6.764	106.44	.2158	6.275	106.42	.2147
120	8.153	107.86	.2206	7.467	107.84	.2194	6.887	107.81	.2182	6.389	107.79	.2171
130	8.297	109.24	.2230	7.600	109.22	.2217	7.009	109.19	.2205	6.503	109.17	.2194
140	8.442	110.63	.2253	7.733	110.61	.2241	7.131	110.58	.2229	6.617	110.56	.2218
150	8.586	112.03	0.2276	7.865	112.01	0.2264	7.254	111.99	0.2252	6.730	111.97	0.2241
160	8.731	113.43	.2299	7.998	113.41	.2287	7.377	113.40	.2275	6.844	113.38	.2264
170	8.875	114.85	.2322	8.130	114.83	.2309	7.499	114.82	.2298	6.958	114.80	.2287
180	9.020	116.28	.2345	8.263	116.26	.2332	7.622	116.25	.2320	7.072	116.23	.2309
190	9.164	117.72	.2367	8.395	117.70	.2354	7.745	117.69	.2343	7.186	117.67	.2332
200	9.307	119.17	0.2389	8.527	119.15	0.2376	7.867	119.14	0.2365	7.300	119.12	0.2354
210	9.451	120.63	.2411	8.659	120.61	.2398	7.989	120.60	.2387	7.413	120.58	.2376
220	9.595	122.10	.2433	8 791	122.08	.2420	8.111	122.07	.2409	7.527	122.05	.2398
230	9.739	123.58	.2455	8.923	123.56	.2442	8.233	123.55	.2430	7.641	123.53	.2419
240	9.883	125.07	.2476	9.056	125.06	.2463	8.355	125.04	.2452	7.755	125.02	.2441
250	10.03	126.58	0.2498	9.188	126.56	0.2485	8.477	126.54	0.2473	7.868	126.53	0.2462
260	10.17	128.09	.2519	9.319	128.07	.2506	8.599	128.06	.2494	7.981	128.04	.2483
270	10.31	129.62	.2540	9.451	129.60	.2527	8.720	129.59	.2515	8.094	129.57	.2504
280	10.46	131.15	.2560	9.583	131.13	.2548	8.841	131.12	.2536	8.207	131.10	.2525
290	10.60	132.70	.2581	9.714	132.68	.2568	8.962	132.67	.2557	8.320	132.65	.2546
300	10.74	134.25	0.2602	9.845	134.24	0.2589	9.084	134.22	0.2577	8.432	134.21	0.2567
310	10.89	135.81	.2622	9.976	135.80	.2609	9.205	135.79	.2589	8.545	135.77	.2587
320	11.03	137.38	.2642	10.11	137.37	.2630	9.327	137.36	.2618	8.658	137.34	.2607
330	11.17	138.96	0.2663	10.24	138.95	.2650	9.448	138.94	.2638	8.771	138.92	.2627
340	.....	.....	.....	10.37	140.54	0.2670	9.570	140.53	0.2658	8.884	140.51	0.2647

Temp. °F.	Abs. Pressure 7.5 lb./in.² Gage Pressure 14.65 in. Vac. (Sat'n. Temp. 42.8°F.)			Abs. Pressure 8.0 lb./in.² Gage Pressure 13.64 in. Vac. (Sat'n. Temp. 45.7°F.)			Abs. Pressure 9.0 lb./in.² Gage Pressure 11.60 in. Vac. (Sat'n. Temp. 51.0°F.)			Abs. Pressure 10.0 lb./in.² Gage Pressure 9.57 in. Vac. (Sat'n. Temp. 55.9°F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(at sat'n)	(5.132)	(97.46)	(0.1970)	(4.833)	(97.80)	(0.1968)	(4.333)	(98.44)	(0.1964)	(3.928)	(99.04)	(0.1960)
50	5.207	98.39	0.1988	4.875	98.36	0.1979	.....	.....	.....	.....	.....	.....
60	5.314	99.70	.2014	4.976	99.67	.2004	4.412	99.62	0.1986	3.961	99.57	0.1970
70	5.422	101.02	.2039	5.077	100.99	.2029	4.502	100.94	.2012	4.042	100.89	.1996
80	5.530	102.35	.2064	5.178	102.32	.2054	4.592	102.28	.2037	4.123	102.23	.2021
90	5.637	103.69	.2088	5.279	103.66	.2079	4.682	103.62	.2061	4.204	103.57	.2045
100	5.745	105.04	0.2113	5.380	105.02	0.2103	4.772	104.98	0.2086	4.285	104.93	0.2070
110	5.851	106.40	.2137	5.480	106.38	.2127	4.862	106.34	.2110	4.366	106.29	.2094
120	5.957	107.77	.2161	5.580	107.75	.2151	4.951	107.71	.2134	4.447	107.67	.2118
130	6.064	109.15	.2184	5.680	109.13	.2175	5.041	109.09	.2157	4.528	109.05	.2141
140	6.170	110.54	.2208	5.780	110.52	.2198	5.131	110.48	.2181	4.609	110.44	.2165
150	6.277	111.94	0.2231	5.880	111.92	0.2221	5.220	111.89	0.2204	4.690	111.85	0.2188
160	6.384	113.35	.2254	5.980	113.34	.2244	5.309	113.30	.2227	4.771	113.26	.2211
170	6.490	114.78	.2277	6.081	114.76	.2267	5.398	114.72	.2250	4.851	114.69	.2234
180	6.597	116.21	.2299	6.181	116.19	.2290	5.487	116.15	.2272	4.932	116.12	.2257
190	6.703	117.65	.2322	6.281	117.63	.2312	5.576	117.59	.2295	5.012	117.56	.2279
200	6.809	119.10	0.2344	6.380	119.08	0.2334	5.665	119.04	0.2317	5.092	119.01	0.2301
210	6.915	120.56	.2366	6.480	120.55	.2356	5.753	120.51	.2339	5.171	120.48	.2323
220	7.021	122.03	.2387	6.579	122.02	.2378	5.842	122.98	.2361	5.251	121.95	.2345
230	7.127	123.51	.2409	6.679	123.50	.2400	5.930	123.46	.2382	5.331	123.43	.2367
240	7.233	125.01	.2431	6.779	124.99	.2421	6.019	124.96	.2404	5.411	124.92	.2388
250	7.339	126.51	0.2452	6.878	126.50	0.2442	6.107	126.46	0.2425	5.491	126.43	0.2409
260	7.445	128.03	.2473	6.977	128.01	.2464	6.196	127.98	.2446	5.571	127.95	.2431
270	7.550	129.55	.2494	7.076	129.54	.2485	6.285	129.51	.2467	5.650	129.48	.2452
280	7.656	131.09	.2515	7.175	131.07	.2506	6.373	131.04	.2488	5.730	131.01	.2473
290	7.761	132.64	.2536	7.274	132.62	.2526	6.461	132.59	.2509	5.809	132.56	.2494
300	7.867	134.19	0.2556	7.373	134.18	0.2547	6.549	134.15	0.2530	5.889	134.12	0.2514
310	7.972	135.76	.2577	7.471	135.74	.2567	6.637	135.71	.2550	5.969	135.68	.2535
320	8.078	137.33	.2597	7.570	137.31	.2588	6.725	137.28	.2570	6.048	137.26	.2555
330	8.183	138.91	.2617	7.668	138.89	.2608	6.813	138.86	.2591	6.127	138.84	.2575
340	8.289	140.50	.2637	7.767	140.49	.2628	6.901	140.46	.2611	6.206	140.43	.2595
350	8.394	142.11	0.2657	7.866	142.10	0.2648	6.988	142.07	0.2631	6.285	142.04	0.2615
360	.....	.....	.....	.....	.....	.....	7.076	143.69	0.2651	6.365	143.66	0.2635

TABLE 2A-11. PROPERTIES OF SUPERHEATED VAPOR, FREON 11 (*Continued*)

Temp. °F.	Abs. Pressure 11.0 lb./in.² Gage Pressure 7.53 in. Vac. (Sat'n. Temp. 60.4°F.)			Abs. Pressure 12.0 lb./in.² Gage Pressure 5.50 in. Vac. (Sat'n. Temp. 64.6°F.)			Abs. Pressure 13 lb./in.² Gage Pressure 3.46 in. Vac. (Sat'n. Temp. 68.5°F.)			Abs. Pressure 14 lb./in.² Gage Pressure 1.42 in. Vac. (Sat'n. Temp. 72.2°F.)		
(at sat'n)	(3.596)	(99.58)	(0.1957)	(3.317)	(100.08)	(0.1955)	(3.079)	(100.55)	(0.1952)	(2.873)	(100.99)	(0.1950)
70	3.666	100.85	0.1982	3.354	100.80	0.1969	3.088	100.75	0.1956	.....	.....	.....
80	3.740	102.18	.2007	3.421	102.13	.1993	3.152	102.09	.1981	2.920	102.04	0.1970
90	3.814	103.52	.2031	3.489	103.48	.2018	3.215	103.43	.2006	2.978	103.38	.1995
100	3.888	104.88	0.2056	3.557	104.84	0.2042	3.278	104.79	0.2030	3.037	104.74	0.2019
110	3.962	106.24	.2080	3.625	106.20	.2066	3.341	106.16	.2055	3.095	106.11	.2043
120	4.036	107.62	.2104	3.693	107.58	.2090	3.405	107.54	.2079	3.154	107.49	.2067
130	4.110	109.01	.2127	3.761	109.97	.2114	3.468	108.92	.2102	3.212	108.88	.2091
140	4.184	110.40	.2151	3.829	110.36	.2138	3.531	110.32	.2126	3.271	110.28	.2114
150	4.257	111.80	0.2174	3.897	111.76	0.2161	3.594	111.73	0.2149	3.329	111.69	0.2138
160	4.331	113.22	.2197	3.964	113.18	.2184	3.656	113.15	.2172	3.388	113.11	.2161
170	4.404	114.65	.2220	4.032	114.61	.2207	3.719	114.58	.2195	3.446	114.54	.2184
180	4.477	116.08	.2242	4.099	116.04	.2230	3.781	116.01	.2218	3.504	115.97	.2206
190	4.551	117.52	.2265	4.166	117.48	.2252	3.843	117.45	.2240	3.562	117.41	.2229
200	4.624	118.97	0.2287	4.233	118.94	0.2274	3.905	118.90	0.2262	3.620	118.87	0.2251
210	4.697	120.44	.2309	4.300	120.41	.2296	3.967	120.37	.2284	3.677	120.34	.2273
220	4.769	121.91	.2331	4.367	121.88	.2318	4.029	121.84	.2306	3.735	121.81	.2295
230	4.842	123.39	.2352	4.433	123.36	.2340	4.090	123.33	.2328	3.792	123.29	.2317
240	4.914	124.89	.2374	4.500	124.86	.2361	4.152	124.83	.2349	3.850	124.79	.2338
250	4.987	126.40	0.2395	4.567	126.36	0.2383	4.214	126.33	0.2371	3.907	126.30	0.2360
260	5.060	127.92	.2417	4.634	127.88	.2404	4.276	127.85	.2392	3.965	127.82	.2381
270	5.132	129.45	.2433	4.701	129.41	.2425	4.337	129.38	.2413	4.022	129.35	.2402
280	5.205	130.98	.2459	4.768	130.95	.2446	4.399	130.92	.2434	4.080	130.89	.2423
290	5.278	132.53	.2479	4.834	132.50	.2467	4.460	132.47	.2455	4.137	132.44	.2444
300	5.350	134.09	0.2500	4.900	134.06	0.2487	4.522	134.03	0.2475	4.195	134.00	0.2464
310	5.422	135.65	.2521	4.966	135.62	.2508	4.583	135.59	.2496	4.252	135.56	.2485
320	5.494	137.23	.2541	5.033	137.20	.2528	4.644	137.17	.2516	4.308	137.14	.2505
330	5.566	138.81	.2561	5.100	138.78	.2548	4.705	138.75	.2537	4.365	138.72	.2526
340	5.639	140.41	.2581	5.166	140.38	.2568	4.767	140.35	.2557	4.422	140.32	.2546
350	5.711	142.02	0.2601	5.232	141.99	0.2588	4.828	141.96	0.2577	4.479	141.94	0.2566
360	5.783	143.64	.2621	5.299	143.61	.2608	4.889	143.58	.2597	4.536	143.56	.2586
370	5.855	145.26	0.2641	5.365	145.23	0.2628	4.950	145.21	0.2616	4.593	145.19	.2605
380	.....	.....	.....	.....	.....	.....	.....	.....	.....	4.651	146.83	0.2625

Temp. °F.	Abs. Pressure 16 lb./in.^{2} Gage Pressure 1.3 lb./in.^{2} (Sat'n. Temp. 79.0°F.)			Abs. Pressure 18 lb./in.^{2} Gage Pressure 3.3 lb./in.^{2} (Sat'n. Temp. 85.2°F.)			Abs. Pressure 20 lb./in.^{2} Gage Pressure 5.3 lb./in.^{2} (Sat'n. Temp. 90.8°F.)			Abs. Pressure 22 lb./in.^{2} Gage Pressure 7.3 lb./in.^{2} (Sat'n. Temp. 96.1°F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(at sat'n)	(2.537)	(101.81)	(0.1947)	(2.274)	(102.55)	(0.1943)	(2.061)	(103.22)	(0.1942)	(1.885)	(103.84)	(0.1940)
80	2.543	101.94	0.1949	.....	.....	.....	.....	.....	.....	.....	.....	.....
90	2.594	103.29	.1974	2.295	103.20	0.1956	.....	.....	.....	.....	.....	.....
100	2.645	104.65	0.1999	2.342	104.56	0.1980	2.099	104.47	0.1964	1.900	104.38	0.1949
110	2.696	106.02	.2023	2.388	105.93	.2005	2.140	105.84	.1989	1.938	105.75	.1974
120	2.748	107.40	.2047	2.434	107.32	.2029	2.182	107.23	.2013	1.976	107.14	.1998
130	2.800	108.80	.2071	2.480	108.71	.2053	2.224	108.63	.2036	2.015	108.54	.2022
140	2.852	110.20	.2094	2.526	110.11	.2076	2.266	110.03	.2060	2.053	109.94	.2045
150	2.903	111.61	0.2118	2.572	111.53	0.2100	2.307	111.44	0.2083	2.091	111.36	0.2069
160	2.954	113.03	.2141	2.618	112.95	.2123	2.349	112.87	.2107	2.129	112.79	.2092
170	3.006	114.46	.2164	2.663	114.38	.2146	2.390	114.31	.2130	2.166	114.23	.2115
180	3.057	115.90	.2186	2.709	115.82	.2168	2.431	115.75	.2152	2.204	115.67	.2138
190	3.108	117.34	.2209	2.755	117.26	.2191	2.473	117.19	.2175	2.242	117.11	.2160
200	3.159	118.79	0.2231	2.801	118.72	0.2213	2.514	118.65	0.2197	2.280	118.57	0.2183
210	3.209	120.26	.2253	2.846	120.19	.2235	2.555	120.12	.2219	2.317	120.05	.2205
220	3.259	121.74	.2275	2.891	121.67	.2257	2.596	121.60	.2241	2.355	121.53	.2227
230	3.310	123.23	.2297	2.936	123.16	.2279	2.637	123.09	.2263	2.392	123.02	.2248
240	3.361	124.73	.2318	2.981	124.66	.2301	2.678	124.59	.2285	2.429	124.53	.2270
250	3.411	126.24	0.2340	3.027	126.17	0.2322	2.719	126.11	0.2306	2.466	126.04	0.2292
260	3.462	127.76	.2361	3.072	127.69	.2343	2.760	127.63	.2328	2.504	127.57	.2313
270	3.513	129.29	.2382	3.117	129.22	.2364	2.800	129.16	.2349	2.541	129.10	.2334
280	3.563	130.83	.2403	3.162	130.76	.2385	2.841	130.70	.2370	2.578	130.64	.2355
290	3.614	132.37	.2424	3.207	132.31	.2406	2.881	132.25	.2391	2.615	132.19	.2376
300	3.664	133.94	0.2445	3.252	133.88	0.2427	2.922	133.82	0.2411	2.652	133.76	0.2397
310	3.714	135.50	.2465	3.296	135.45	.2447	2.962	135.39	.2432	2.689	135.33	.2417
320	3.764	137.08	.2486	3.341	137.03	.2468	3.003	136.97	.2452	2.726	136.91	.2438
330	3.814	138.67	.2506	3.385	138.61	.2488	3.043	138.56	.2472	2.763	138.50	.2458
340	3.864	140.27	.2526	3.430	140.21	.2508	3.084	140.16	.2493	2.800	140.10	.2478
350	3.914	141.88	0.2546	3.475	141.83	0.2528	3.124	141.77	0.2513	2.837	141.72	0.2498
360	3.964	143.50	.2566	3.520	143.45	.2548	3.164	143.40	.2532	2.874	143.34	.2518
370	4.015	145.13	.2586	3.565	145.08	.2568	3.205	145.03	.2552	2.910	144.97	.2538
380	4.066	146.78	0.2605	3.610	146.73	.2588	3.245	146.68	.2572	2.947	146.62	.2558
390	.....	.....	.....	3.654	148.38	0.2607	3.286	148.33	.2592	2.984	148.28	.2577
00	.....	.....	.....	.....	.....	.....	3.326	149.99	0.2611	3.021	149.94	0.2597

TABLE 2A-11. PROPERTIES OF SUPERHEATED VAPOR, FREON 11 (*Continued*)

Temp. °F.	Abs. Pressure 24 lb./in.² Gage Pressure 9.3 lb./in.² (Sat'n. Temp. 100.9°F.)			Abs. Pressure 26 lb./in.² Gage Pressure 11.3 lb./in.² (Sat'n. Temp. 105.5°F.)			Abs. Pressure 28 lb./in.² Gage Pressure 13.3 lb./in.² (Sat'n. Temp. 109.8°F.)			Abs. Pressure 30 lb./in.² Gage Pressure 15.3 lb./in.² (Sat'n. Temp. 113.9°F.)		
(at sat'n)	(1.738)	(104.41)	(0.1938)	(1.612)	(104.94)	(0.1937)	(1.504)	(105.45)	(0.1935)	(1.409)	(105.93)	(0.1935)
110	1.769	105.66	0.1960	1.626	105.57	0.1947	1.504	105.48	0.1936	.....	.....	.....
120	1.805	107.05	.1984	1.659	106.96	.1972	1.535	106.87	.1960	1.426	106.79	0.1949
130	1.840	108.45	.2008	1.692	108.36	.1996	1.566	108.27	.1984	1.455	108.19	.1973
140	1.875	109.86	.2032	1.725	109.77	.2019	1.596	109.69	.2008	1.484	109.60	.1997
150	1.910	111.28	0.2055	1.757	111.19	0.2043	1.626	111.11	0.2031	1.513	111.02	0.2020
160	1.945	112.70	.2079	1.790	112.62	.2066	1.657	112.54	.2054	1.541	112.45	.2044
170	1.980	114.14	.2102	1.822	114.06	.2089	1.687	113.98	.2077	1.569	113.90	.2067
180	2.015	115.59	.2124	1.854	115.51	.2112	1.717	115.43	.2100	1.598	115.35	.2090
190	2.049	117.04	.2147	1.887	116.96	.2135	1.747	116.88	.2123	1.626	116.81	.2112
200	2.084	118.50	0.2169	1.919	118.42	0.2157	1.777	118.35	0.2146	1.654	118.27	0.2135
210	2.119	119.98	.2192	1.951	119.90	.2179	1.807	119.83	.2168	1.682	119.75	.2157
220	2.154	121.46	.2214	1.983	121.39	.2201	1.837	121.32	.2190	1.711	121.24	.2179
230	2.188	122.96	.2235	2.015	122.88	.2223	1.867	122.81	.2212	1.739	122.74	.2201
240	2.222	124.46	.2257	2.047	124.39	.2245	1.897	124.32	.2233	1.767	124.25	.2223
250	2.256	125.97	0.2279	2.079	125.91	0.2266	1,926	125.84	0.2255	1.794	125.77	0.2244
260	2.291	127.50	.2300	2.111	127.44	.2288	1.956	127.37	.2276	1.822	127.30	.2266
270	2.325	129.03	.2321	2.142	128.97	.2309	1.986	128.91	.2298	1.850	128.84	.2287
280	2.359	130.58	.2342	2.174	130.52	.2330	2.015	130.46	.2319	1.878	130.39	.2308
290	2.393	132.13	.2363	2.206	132.07	.2351	2.045	132.01	.2340	1.905	131.95	.2329
300	2.427	133.70	0.2384	2.238	133.64	0.2372	2.074	133.58	0.2360	1.933	133.52	0.2350
310	2.461	135.27	.2404	2.269	135.22	.2392	2.103	135.16	.2381	1.960	135.10	.2370
320	2.495	136.85	.2425	2.300	136.80	.2413	2.133	136.74	.2401	1.988	136.68	.2391
330	2.529	138.44	.2445	2.332	138.39	.2433	2.162	138.33	.2422	2.015	138.28	.2411
340	2.563	140.04	.2465	2.363	139.99	.2453	2.192	139.94	.2442	2.043	139.89	.2431
350	2.597	141.66	0.2485	2.394	141.61	0.2473	2.221	141.56	0.2462	2.070	141.51	0.2452
360	2.631	143.29	.2505	2.426	143.24	.2493	2.250	143.19	.2482	2.097	143.14	.2472
370	2.665	144.92	.2525	2.457	144.87	.2513	2.279	144.83	.2502	2.125	144.78	.2491
380	2.699	146.57	.2545	2.488	146.52	.2533	2.308	146.48	.2522	2.152	146.43	.2511
390	2.733	148.23	.2564	2.520	148.18	.2552	2.337	148.14	.2541	2.179	148.09	.2531
400	2.767	149.90	0.2584	2.551	149.85	0.2572	2.367	149.80	0.2561	2.207	149.75	0.2550
410	2.801	151.58	0.2603	2.583	151.53	0.2591	2.396	151.48	0.2580	2.234	151.43	.2570
420	.....	.....	.....	.....	.....	.....	.....	.....	.....	2.261	153.12	0.2589

Temp. °F.	Abs. Pressure 35 lb./in.² Gage Pressure 20.3 lb./in.² (Sat'n. Temp. 123.3°F.)			Abs. Pressure 40 lb./in.² Gage Pressure 25.3 lb./in.² (Sat'n. Temp. 131.6°F.)			Abs. Pressure 45 lb./in.² Gage Pressure 30.3 lb./in.² (Sat'n. Temp. 139.3°F.)			Abs. Pressure 50 lb./in.² Gage Pressure 35.3 lb./in.² (Sat'n. Temp. 146.3°F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(at sat'n)	(1.219)	(107.01)	(0.1932)	(1.074)	(107.96)	(0.1930)	(0.9608)	(108.84)	(0.1929)	(0.8689)	(109.62)	(0.1928)
130	1.235	107.97	0.1948	.....	.....	.....	.....	.....	.....	.....	.....	.....
140	1.260	109.39	.1972	1.092	109.17	0.1950	0.9621	108.95	0.1931	.....	.....	.....
150	1.285	110.81	0.1996	1.115	110.60	0.1974	0.9824	110.39	0.1955	0.8756	110.16	0.1937
160	1.310	112.25	.2019	1.137	112.04	.1997	1.002	111.83	.1978	.8937	111.61	.1960
170	1.335	113.70	.2042	1.159	113.49	.2021	1.022	113.29	.2001	.9118	113.08	.1984
180	1.360	115.15	.2065	1.181	114.95	.2044	1.042	114.75	.2024	.9299	114.55	.2007
190	1.384	116.61	.2088	1.202	116.42	.2067	1.061	116.22	.2047	.9477	116.03	.2030
200	1.409	118.08	0.2111	1.224	117.89	0.2089	1.081	117.70	0.2070	0.9656	117.52	0.2053
210	1.433	119.57	.2133	1.246	119.38	.2112	1.100	119.20	.2093	0.9835	119.02	.2075
220	1.458	121.06	.2155	1.268	120.88	.2134	1.120	120.70	.2115	1.002	120.52	.2098
230	1.482	122.57	.2177	1.289	122.39	.2156	1.139	122.21	.2137	1.019	122.04	.2120
240	1.506	124.08	.2199	1.311	124.91	.2178	1.159	123.73	.2159	1.037	123.56	.2142
250	1.530	125.61	0.2220	1.332	125.44	0.2199	1.178	125.27	0.2181	1.054	125.10	0.2164
260	1.554	127.14	.2242	1.353	126.97	.2221	1.197	126.81	.2202	1.072	126.64	.2185
270	1.578	128.68	.2263	1.374	128.52	.2242	1.216	128.36	.2224	1.089	128.20	.2207
280	1.602	130.23	.2284	1.396	130.08	.2263	1.235	129.92	.2245	1.106	129.76	.2228
290	1.626	131.80	.2305	1.417	131.64	.2284	1.254	131.49	.2266	1.124	131.33	.2249
300	1.650	133.37	0.2326	1.438	133.22	0.2305	1.273	133.07	0.2287	1.141	132.91	0.2270
310	1.674	134.95	.2347	1.459	134.80	.2326	1.292	134.65	.2307	1.158	134.50	.2291
320	1.698	136.54	.2367	1.480	136.40	.2347	1.311	136.25	.2328	1.175	136.10	.2311
330	1.721	138.14	.2388	1.501	138.00	.2367	1.330	137.86	.2349	1.192	137.71	.2332
340	1.745	139.75	.2408	1.522	139.61	.2387	1.348	139.47	.2369	1.209	139.33	.2352
350	1.769	141.38	0.2428	1.543	141.24	0.2407	1.367	141.10	0.2389	1.226	140.96	0.2373
360	1.792	143.01	.2448	1.564	142.88	.2427	1.386	142.74	.2409	1.243	142.61	.2393
370	1.816	144.65	.2468	1.584	144.52	.2447	1.404	144.39	.2429	1.260	144.26	.2413
380	1.840	146.30	.2488	1.605	146.18	.2467	1.423	146.05	.2449	1.277	145.92	.2433
390	1.863	147.96	.2507	1.626	147.83	.2487	1.442	147.71	.2469	1.294	147.58	.2452
400	1.887	149.63	0.2527	1.647	149.51	0.2506	1.460	149.38	0.2488	1.311	149.26	0.2472
410	1.910	151.31	.2546	1.668	151.19	.2526	1.479	151.07	.2508	1.328	150.95	.2492
420	1.934	153.00	.2566	1.688	152.89	.2545	1.498	152.77	.2527	1.345	152.65	.2511
430	1.957	154.70	0.2585	1.709	154.59	.2564	1.516	154.47	.2547	1.361	154.36	.2530
440	.....	.....	.....	1.729	156.30	0.2583	1.534	156.19	0.2566	1.378	156.07	.2549
450	.....	.....	.....	.....	.....	.....	.....	.....	.....	1.395	157.80	0.2569

TABLE 2A-11. PROPERTIES OF SUPERHEATED VAPOR, FREON 11 (*Continued*)

Temp. °F.	Abs. Pressure 55 lb./in.² Gage Pressure 40.3 lb./in.² (Sat'n. Temp 152.8°F.)			Abs. Pressure 60 lb./in.² Gage Pressure 45.3 lb./in.² (Sat'n. Temp. 158.8°F.)			Abs. Pressure 65 lb./in.² Gage Pressure 50.3 lb./in.² (Sat'n. Temp. 164.5°F.)		
(at sat'n)	(0.7933)	(110.33)	(0.1927)	(0.7297)	(110.99)	(0.1926)	(0.6755)	(111.61)	(0.1926)
160	0.8054	111.39	0.1944	0.7314	111.17	0.1929	.....	.....	.....
170	.8222	112.86	.1968	.7471	112.65	.1953	0.6835	112.44	0.1939
180	.8389	114.34	.1991	.7627	114.14	.1976	.6982	113.93	.1963
190	.8554	115.83	.2014	.7782	115.63	.1999	.7129	115.42	.1986
200	0.8720	117.33	0.2037	0.7937	117.13	0.2022	0.7273	116.93	0.2009
210	.8884	118.83	.2060	.8090	118.64	.2045	.7417	118.44	.2032
220	.9048	120.34	.2082	.8241	120.16	.2068	.7561	119.96	.2054
230	.9210	121.86	.2104	.8391	121.68	.2090	.7701	121.49	.2077
240	.9372	123.39	.2126	.8541	123.21	.2112	.7841	123.04	.2099
250	0.9534	124.93	0.2148	0.8691	124.76	0.2134	0.7980	124.59	0.2121
260	0.9695	126.48	.2170	.8839	126.31	.2156	.8119	126.15	.2142
270	0.9853	128.04	.2191	.8987	127.87	.2177	.8255	127.71	.2164
280	1.001	129.60	.2213	.9134	129.44	.2198	.8391	129.27	.2185
290	1.017	131.17	.2234	.9281	131.01	.2220	.8529	131.85	.2207
300	1.033	132.76	0.2255	0.9427	132.60	0.2241	0.8667	132.45	0.2228
310	1.049	134.35	.2276	.9574	134.20	.2262	.8803	134.05	.2249
320	1.065	135.96	.2296	.9719	135.81	.2282	.8939	135.66	.2269
330	1.080	137.57	.2317	0.9863	137.42	.2303	.9073	137.28	.2290
340	1.096	139.19	.2337	1.001	139.05	.2323	.9207	138.91	.2311
350	1.111	140.83	0.2358	1.015	140.69	0.2344	0.9341	140.55	0.2331
360	1.127	142.47	.2378	1.030	142.33	.2364	.9474	142.20	.2351
370	1.142	144.12	.2398	1.044	143.98	.2384	.9608	143.85	.2371
380	1.158	145.78	.2418	1.059	145.65	.2404	.9742	145.52	.2391
390	1.173	147.45	.2437	1.073	147.32	.2424	0.9875	147.19	.2411
400	1.189	149.13	0.2457	1.087	149.01	0.2443	1.001	148.88	0.2431
410	1.204	150.83	.2477	1.101	150.70	.2463	1.014	150.58	.2450
420	1.220	152.53	.2496	1.115	152.41	.2483	1.027	152.29	.2470
430	1.235	154.24	.2515	1.130	154.12	.2502	1.040	154.01	.2489
440	1.250	155.96	.2535	1.144	155.84	.2521	1.053	155.73	.2509
450	1.265	157.68	0.2554	1.158	157.57	0.2540	1.066	157.46	0.2528
460	1.281	159.42	0.2573	1.172	159.31	0.2559	1.080	159.20	.2547
470	.....	.....	.....	.....	.....	.....	1.093	160.96	0.2566

DICHLORODIFLUOROMETHANE, FREON 12

TABLE 2A-12. PROPERTIES OF SATURATED VAPOR, FREON 12

Temp. °F. t	Pressure		Volume		Density		Enthalpy from −40°F.			Entropy from −40°F.		Temp. °F. t
	Absolute lbs./in.^{2} p	Gage lbs./in.^{2} $g.p.$	Liquid ft.^{3}/lb. v_f	Vapor ft.^{3}/lb. v_g	Liquid lbs./ft.^{3} $1/v_f$	Vapor lbs./ft.^{3} $1/v_g$	Liquid Btu./lb. h_f	Latent Btu./lb. h_{fg}	Vapor Btu./lb. h_g	Liquid Btu /lb °F s_f	Vapor Btu /lb.°F. s_g	
−155	0.1163	29.68	0.00954	232.29	104.86	0.004305	−24.61	84.61	60.00	−0.0686	0.2092	−155
−150	0.1527	29.61	0.00957	179.79	104.46	0.005562	−23.50	84.07	60.57	−0.0650	0.2065	−150
−145	.1985	29.52	.00961	140.52	104.05	.007117	−22.39	83.53	61.14	− .0615	.2040	−145
−140	.2554	29.40	.00965	110.92	103.64	.009016	−21.29	83.01	61.72	− .0580	.2017	−140
−135	.3256	29.26	.00969	88.34	103.22	.01132	−20.19	82.49	62.30	− .0546	.1995	−135
−130	.4116	29.08	.00973	70.94	102.80	.01410	−19.10	81.98	62.88	− .0512	.1975	−130
−125	0.5160	28.87	0.00977	57.42	102.38	0.01742	−18.02	81.48	63.46	−0.0480	0.1955	−125
−120	.6417	28.61	.00981	46.84	101.95	.02135	−16.94	80.98	64.04	− .0448	.1937	−120
−115	.7921	28.31	.00985	38.49	101.52	.02598	−15.85	80.48	64.63	− .0416	.1919	−115
−110	.9709	27.94	.00989	31.84	101.08	.03141	−14.78	80.00	65.22	− .0385	.1903	−110
−105	1.182	27.51	.00994	26.51	100.64	.03773	−13.71	79.52	65.81	− .0355	.1888	−105
−100	1.430	27.01	0.00998	22.20	100.20	0.04504	−12.64	79.04	66.40	−0.0325	0.1873	−100
−95	1.719	26.42	.01003	18.71	99.75	.05344	−11.58	78.57	66.99	− .0295	.1860	−95
−90	2.054	25.74	.01007	15.86	99.30	.06305	−10.51	78.10	67.59	− .0266	.1847	−90
−85	2.441	24.95	.01012	13.51	98.85	.07400	−9.46	77.64	68.18	− .0238	.1835	−85
−80	2.885	24.05	.01016	11.57	98.39	.08640	−8.40	77.17	68.77	− .0210	.1823	−80

−75	3.398	23.01	0.01021	9.958	97.92	0.1004	−7.35	76.71	69.36	−0.0182	0.1813	−75
−70	3.971	21.84	.01026	8.608	97.46	.1162	−6.30	76.25	69.95	− .0155	.1802	−70
−65	4.626	20.50	.01031	7.474	96.99	.1338	−5.25	75.79	70.54	− .0128	.1793	−65
−60	5.365	19.00	.01036	6.516	96.51	.1535	−4.20	75.33	71.13	− .0102	.1783	−60
−55	6.195	17.31	.01041	5.704	96.04	.1753	−3.15	74.87	71.72	− .0076	.1774	−55
−50	7.125	15.42	0.01047	5.012	95.55	0.1995	−2.11	74.42	72.31	−0.0050	0.1767	−50
−45	8.163	13.31	.01052	4.420	95.07	.2263	−1.06	73.97	72.91	− .0025	.1759	−45
−40	9.32	10.92*	0.0106	3.911	94.58	0.2557	0	73.50	73.50	0	0.17517	−40
−38	9.82	9 91*	.0106	3.727	94.39	2683	0.40	73.34	73.74	0.00094	.17490	−38
−36	10.34	8.87*	0106	3.553	94.20	.2815	0.81	73.17	73.98	.00188	.17463	−36
−34	10.87	7.80*	0106	3.389	93.99	.2951	1.21	73.01	74.22	.00282	.17438	−34
−32	11.43	6.66*	0107	3.234	93.79	.3092	1.62	72.84	74.46	.00376	17412	−32
−30	12.02	5.45*	0.0107	3.088	93.59	0.3238	2.03	72 67	74.70	0.00471	0.17387	−30
−28	12.62	4.23*	.0107	2.950	93.39	.3390	2.44	72.50	74.94	.00565	.17364	−28
−26	13.26	2.93*	.0107	2.820	93.18	.3546	2.85	72.33	75.18	.00659	17340	−26
−24	13.90	1.63*	.0108	2.698	92.98	.3706	3.25	72.16	75.41	.00753	17317	−24
−22	14.58	0.24*	.0108	2.583	92.78	.3871	3.66	71.98	75.64	.00846	17296	−22
−20	15.28	0.58	0.0108	2.474	92.58	0.4042	4.07	71.80	75.87	0.00940	0.17275	−20
−18	16.01	1.31	.0108	2.370	92.38	4219	4.48	71.63	76.11	.01033	17253	−18
−16	16.77	2.07	.0108	2.271	92.18	4403	4.89	71.45	76.34	.01126	.17232	−16
−14	17.55	2.85	.0109	2.177	91.97	4593	5.30	71.27	76.57	01218	.17212	−14
−12	18.37	3.67	.0109	2.088	91.77	4789	5.72	71.09	76.81	01310	17194	−12
−10	19.20	4.50	0.0109	2.003	91.57	0.4993	6.14	70.91	77.05	0.01403	0.17175	−10
−8	20.08	5.38	.0109	1.922	91.35	5203	6.57	70.72	77 29	.01496	.17158	−8
−6	20 98	6.28	.0110	1.845	91.14	.5420	6.99	70 53	77.52	.01589	17140	−6
−4	21.91	7.21	.0110	1.772	90.93	.5644	7 41	70.34	77.75	.01682	.17123	−4
−2	22.87	8 17	.0110	1.703	90.72	.5872	7.83	70.15	77 98	.01775	17107	−2

* Inches of mercury below one atmosphere.

TABLE 2A-12. PROPERTIES OF SATURATED VAPOR, FREON 12 (*Continued*)

Temp. °F. t	Pressure		Volume		Density		Enthalpy from −40°F.			Entropy from −40°F.		Temp. °F. t
	Absolute lbs./in.² p	Gage lbs./in.² $g.p.$	Liquid ft.³/lb. v_f	Vapor ft.³/lb. v_g	Liquid lbs./ft.³ $1/v_f$	Vapor lbs./ft.³ $1/v_g$	Liquid Btu./lb. h_f	Latent Btu./lb. h_{fg}	Vapor Btu./lb. h_g	Liquid Btu./lb.°F. s_f	Vapor Btu./lb.°F. s_g	
0	23.87	9.17	0.0110	1.637	90.52	0.6109	8.25	69.96	78.21	0.01869	0.17091	0
2	24.89	10.19	.0110	1.574	90.31	.6352	8.67	69.77	78.44	.01961	.17075	2
4	25.96	11.26	.0111	1.514	90.11	.6606	9.10	69.57	78.67	.02052	.17060	4
5†	**26.51**	**11.81**	**.0111**	**1.485**	**90.00**	**.6735**	**9.32**	**69.47**	**78.79**	**.02097**	**.17052**	**5†**
6	27.05	12.35	.0111	1.457	89.88	.6864	9.53	69.37	78.90	.02143	.17045	6
8	28.18	13.48	.0111	1.403	89.68	.7129	9.96	69.17	79.13	.02235	.17030	8
10	29.35	14.65	0.0112	1.351	89.45	0.7402	10.39	68.97	79.36	0.02328	0.17015	10
12	30.56	15.86	.0112	1.301	89.24	.7687	10.82	68.77	79.59	.02419	.17001	12
14	31.80	17.10	.0112	1.253	89.03	.7981	11.26	68.56	79.82	.02510	.16987	14
16	33.08	18.38	.0112	1.207	88.81	.8288	11.70	68.35	80.05	.02601	.16974	16
18	34.40	19.70	.0113	1.163	88.58	.8598	12.12	68.15	80.27	.02692	.16961	18
20	35.75	21.05	0.0113	1.121	88.37	0.8921	12.55	67.94	80.49	0.02783	0.16949	20
22	37.15	22.45	.0113	1.081	88.13	.9251	13.00	67.72	80.72	.02873	.16938	22
24	38.58	23.88	.0113	1.043	87.91	.9588	13.44	67.51	80.95	.02963	.16926	24
26	40.07	25.37	.0114	1.007	87.68	.9930	13.88	67.29	81.17	.03053	.16913	26
28	41.59	26.89	.0114	0.973	87.47	1.028	14.32	67.07	81.39	.03143	.16900	28
30	43.16	28.46	0.0115	0.939	87.24	1.065	14.76	66.85	81.61	0.03233	0.16887	30
32	44.77	30.07	.0115	.908	87.02	1.102	15.21	66.62	81.83	.03323	.16876	32
34	46.42	31.72	.0115	.877	86.78	1.140	15.65	66.40	82.05	.03413	.16865	34
36	48.13	33.43	.0116	.848	86.55	1.180	16.10	66.17	82.27	.03502	.16854	36
38	49.88	35.18	.0116	.819	86.33	1.221	16.55	65.94	82.49	.03591	.16843	38

40	51.68	36.98	0.0116	0.792	86.10	1.263	17.00	65.71	82.71	0.03680	0.16833	40
42	53.51	38.81	.0116	.767	85.88	1.304	17.46	65.47	82.93	.03770	.16823	42
44	55.40	40.70	.0117	.742	85.66	1.349	17.91	65.24	83.15	.03859	.16813	44
46	57.35	42.65	.0117	.718	85.43	1.393	18.36	65.00	83.36	.03948	.16803	46
48	59.35	44.65	.0117	.695	85.19	1.438	18.82	64.74	83.57	.04037	.16794	48
50	61.39	46.69	0.0118	0.673	84.94	1.485	19.27	64.51	83.78	0.04126	0.16785	50
52	63.49	48.79	.0118	.652	84.71	1.534	19.72	64.27	83.99	.04215	.16776	52
54	65.63	50.93	.0118	.632	84.50	1.583	20.18	64.02	84.20	.04304	.16767	54
56	67.84	53.14	.0119	.612	84.28	1.633	20.64	63.77	84.41	.04392	.16758	56
58	70.10	55.40	.0119	.593	84.04	1.686	21.11	63.51	84.62	.04480	.16749	58
60	72.41	57.71	0.0119	0.575	83.78	1.740	21.57	63.25	84.82	0.04568	0.16741	60
62	74.77	60.07	.0120	.557	83.57	1.795	22.03	62.99	85.02	.04657	.16733	62
64	77.20	62.50	.0120	540	83.34	1.851	22.49	62.73	85.22	.04745	.16725	64
66	79.67	64.97	.0120	524	83.10	1 909	22.95	62.47	85.42	.04833	.16717	66
68	82.24	67.54	0121	508	82.86	1.968	23.42	62.20	85.62	.04921	.16709	68
70	84 82	70.12	0.0121	0.493	82.60	2.028	23 90	61.92	85.82	0.05009	0.16701	70
72	87 50	72 80	.0121	479	82.37	2.090	24 37	61.65	86.02	.05097	.16693	72
74	90 20	75.50	.0122	.464	82.12	2.153	24 84	61.38	86.22	.05185	.16685	74
76	93.00	78.30	.0122	.451	81.87	2.218	25.32	61.10	86.42	.05272	.16677	76
78	95 85	81.15	.0123	.438	81.62	2.284	25.80	60.81	86.61	.05359	.16669	78
80	98.76	84.06	0.0123	0.425	81.39	2.353	26.28	60.52	86.80	0.05446	0.16662	80

† Standard ton temperature.

TABLE 2A-12. PROPERTIES OF SATURATED VAPOR, FREON 12 (*Continued*)

Temp. °F. t	Pressure		Volume		Density		Enthalpy from −40°F.			Entropy from −40°F.		Temp. °F. t
	Absolute lbs./in.² p	Gage lbs./in.² $g.p.$	Liquid ft.³/lb. v_f	Vapor ft.³/lb. v_g	Liquid lbs./ft.³ $1/v_f$	Vapor lbs./ft.³ $1/v_g$	Liquid Btu./lb. h_f	Latent Btu./lb. h_{fg}	Vapor Btu./lb. h_g	Liquid Btu/lb.°F s_f	Vapor Btu/lb.°F. s_g	
80	98.76	84.06	0.0123	0.425	81.39	2.353	26.28	60.52	86.80	0.05446	0.16662	80
82	101.7	87.00	.0123	.413	81.12	2.423	26.76	60.23	86.99	.05534	.16655	82
84	104.8	90.1	.0124	.401	80.87	2.495	27.24	59.94	87.18	.05621	.16648	84
86†	107.9	93.2	.0124	.389	80.63	2.569	27.72	59.65	87.37	.05708	.16640	86†
88	111.1	96.4	.0124	.378	80.37	2.645	28.21	59.35	87.56	.05795	.16632	88
90	114.3	99.6	0.0125	0.368	80.11	2.721	28.70	59.04	87.74	0.05882	0.16624	90
92	117.7	103.0	.0125	.357	79.86	2.799	29.19	58.73	87.92	.05969	.16616	92
94	121.0	106.3	.0126	.347	79.60	2.880	29.68	58.42	88.10	.06056	.16608	94
96	124.5	109.8	.0126	.338	79.32	2.963	30.18	58.10	88.28	.06143	.16600	96
98	128.0	113.3	.0126	.328	79.06	3.048	30.67	57.78	88.45	.06230	.16592	98
100	131.6	116.9	0.0127	0.319	78.80	3.135	31.16	57.46	88.62	0.06316	0.16584	100
102	135.3	120.6	.0127	.310	78.54	3.224	31.65	57.14	88.79	.06403	.16576	102
104	139.0	124.3	.0128	.302	78.27	3.316	32.15	56.80	88.95	.06490	.16568	104
106	142.8	128.1	.0128	.293	78.00	3.411	32.65	56.46	89.11	.06577	.16560	106
108	146.8	132.1	.0129	.285	77.73	3.509	33.15	56.12	89.27	.06663	.16551	108

110	150.7	136.0	0.0129	0.277	77.46	3.610	33.65	55.78	89.43	0.06749	0.16542	110
112	154.8	140.1	.0130	.269	77.18	3.714	34.15	55.43	89.58	.06836	.16533	112
114	158.9	144.2	.0130	.262	76.89	3.823	34.65	55.08	89.73	.06922	.16524	114
116	163.1	148.4	.0131	.254	76.60	3.934	35.15	54.72	89.87	.07008	.16515	116
118	167.4	152.7	.0131	.247	76.32	4.049	35.65	54.36	90.01	.07094	.16505	118
120	171.8	157.1	0.0132	0.240	76.02	4.167	36.16	53.99	90.15	0.07180	0.16495	120
122	176.2	161.5	.0132	.233	75.72	4.288	36.66	53.62	90.28	.07266	.16484	122
124	180.8	166.1	.0133	.227	75.40	4.413	37.16	53.24	90.40	.07352	.16473	124
126	185.4	170.7	.0133	.220	75.10	4.541	37.67	52.85	90.52	.07437	.16462	126
128	190.1	175.4	.0134	.214	74.78	4.673	38.18	52.46	90.64	.07522	.16450	128
130	194.9	180.2	0.0134	0.208	74.46	4.808	38.69	52.07	90.76	0.07607	0.16438	130
132	199.8	185.1	.0135	.202	74.13	4.948	39.19	51.67	90.86	.07691	.16425	132
134	204.8	190.1	.0135	.196	73.81	5.094	39.70	51.26	90.96	.07775	.16411	134
136	209.9	195.2	.0136	.191	73.46	5.247	40.21	50.85	91.06	.07858	.16396	136
138	215.0	200.3	.0137	.185	73.10	5.405	40.72	50.43	91.15	.07941	.16380	138
140	220.2	205.5	0.0138	0.180	72.73	5.571	41.24	50.00	91.24	0.08024	0.16363	140

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† Standard ton temperature.

TABLE 2A-13. PROPERTIES OF SUPERHEATED VAPOR, FREON 12

Temp. °F.	Abs. Pressure 0.14 lbs./in.² Gage Pressure 29.64 ins. vac. (Sat'n. Temp. −151.7°F.)			Abs. Pressure 0.16 lbs./in.² Gage Pressure 29.59 ins. vac. (Sat'n. Temp. −149.2°F.)			Abs. Pressure 0.18 lbs./in.² Gage Pressure 29.55 ins. vac. (Sat'n. Temp. −147.0°F.)			Abs. Pressure 0.20 lbs./in.² Gage Pressure 29.51 ins. vac. (Sat'n. Temp. −144.9°F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(at sat'n)	(195.0)	(60.37)	(0.2075)	(172.0)	(60.66)	(0.2062)	(154.0)	(60.91)	(0.2051)	(139.5)	(61.16)	(0.2040)
−150	196.1	60.57	0.2080	--------	--------	--------	--------	--------	--------	--------	--------	--------
−140	202.5	61.73	.2117	177.1	61.72	0.2095	157.4	61.72	0.2076	141.7	61.72	0.2059
−130	208.8	62.89	.2153	182.7	62.89	.2131	162.4	62.89	.2112	146.1	62.89	.2094
−120	215.2	64.08	.2188	188.3	64.07	.2166	167.3	64.07	.2147	150.6	64.07	.2129
−110	221.5	65.27	.2222	193.8	65.27	.2201	172.3	65.27	.2181	155.0	65.27	.2164
−100	227.9	66.48	0.2256	199.4	66.48	0.2235	177.2	66.48	0.2215	159.5	66.47	0.2198
− 90	234.2	67.70	.2290	204.9	67.70	.2268	182.1	67.70	.2249	163.9	67.70	.2231
− 80	240.5	68.93	.2323	210.5	68.93	.2301	187.1	68.93	.2282	168.3	68.93	.2264
− 70	246.9	70.18	.2355	216.0	70.18	.2334	192.0	70.18	.2314	172.8	70.18	.2297
− 60	253.2	71.44	.2387	221.6	71.44	.2365	196.9	71.44	.2346	177.2	71.44	.2329
− 50	259.6	72.72	0.2419	227.1	72.72	0.2397	201.9	72.71	0.2377	181.7	72.71	0.2360
− 40	265.9	74.00	.2450	232.7	74.00	.2428	206.8	74.00	.2408	186.1	74.00	.2391
− 30	272.3	75.31	.2480	238.2	75.30	.2458	211.7	75.30	.2439	190.6	75.30	.2422
− 20	278.6	76.62	.2511	243.8	76.62	.2489	216.7	76.62	.2469	195.0	76.62	.2452
− 10	284.9	77.95	.2541	249.3	77.95	.2519	221.6	77.94	.2499	199.4	77.94	.2482
0	291.3	79.29	0.2570	254.9	79.29	0.2548	226.5	79.29	0.2529	203.9	79.29	0.2511
10	297.6	80.64	.2599	260.4	80.64	.2577	231.5	80.64	.2558	208.3	80.64	.2541
20	304.0	82.01	.2628	266.0	82.01	.2606	236.4	82.01	.2587	212.8	82.01	.2569
30	310.3	83.39	.2656	271.5	83.39	.2635	241.3	83.39	.2615	217.2	83.39	.2598
40	316.7	84.78	.2685	277.1	84.78	.2663	246.3	84.78	.2643	221.6	84.78	.2626
50	323.0	86.19	0.2713	282.6	86.19	0.2691	251.2	86.19	0.2671	226.1	86.19	0.2654
60	329.3	87.61	.2740	288.2	87.61	.2718	256.1	87.61	.2699	230.5	87.61	.2682
70	335.7	89.05	.2767	293.7	89.04	.2746	261.1	89.04	.2726	235.0	89.04	.2709
80	342.0	90.49	.2795	299.3	90.49	.2773	266.0	90.49	.2753	239.4	90.49	.2736
90	348.4	91.95	.2821	304.8	91.95	.2799	270.9	91.95	.2780	243.8	91.95	.2763
100	354.7	93.43	0.2848	310.4	93.43	0.2826	275.9	93.43	0.2807	248.3	93.42	0.2789
110	361.1	94.91	.2874	315.9	94.91	.2852	280.8	94.91	.2833	252.7	94.91	.2816
120	367.4	96.41	.2901	321.5	96.41	.2879	285.7	96.41	.2859	257.2	96.41	.2842
130	373.7	97.93	.2926	327.0	97.93	.2904	290.7	97.93	.2885	261.6	97.93	.2868
140	380.1	99.45	.2952	332.6	99.45	.2930	295.6	99.45	.2911	266.0	99.45	.2893
150	386.4	101.00	0.2978	338.1	100.99	0.2956	300.5	100.99	0.2936	270.5	100.99	0.2919
160	--------	--------	--------	343.7	102.55	.2981	305.5	102.55	.2962	274.9	102.55	.2944

Temp. °F.	Abs. Pressure 0.25 lbs./in.² Gage Pressure 29.41 ins. vac. (Sat'n. Temp. −140.5°F.)			Abs. Pressure 0.30 lbs./in.² Gage Pressure 29.31 ins. vac. (Sat'n. Temp. −136.8°F.)			Abs. Pressure 0.35 lbs./in.² Gage Pressure 29.21 ins. vac. (Sat'n. Temp. −133.6°F.)			Abs. Pressure 0.40 lbs./in.² Gage Pressure 29.11 ins. vac. (Sat'n. Temp. −130.7°F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(at sat'n)	(113.1)	(61.66)	(0.2020)	(95.36)	(62.09)	(0.2004)	(82.53)	(62.46)	(0.1990)	(72.84)	(62.80)	(0.1978)
—140	113.3	61.72	0.2022	....	....	....	....	....	....	....	....	....
—130	116.9	62.89	.2058	97.37	62.89	0.2028	83.45	62.88	0.2002	73.00	62.88	0.1980
—120	120.4	64.07	.2093	100.3	64.06	.2063	85.99	64.06	.2037	75.22	64.06	.2015
—110	124.0	65.26	.2127	103.3	65.26	.2097	88.53	65.26	.2072	77.45	65.25	.2050
—100	127.5	66.47	.2161	106.3	66.47	.2131	91.07	66.46	.2106	79.67	66.46	.2084
— 90	131.1	67.69	0.2195	109.2	67.69	0.2165	93.61	67.69	0.2139	81.90	67.68	0.2117
— 80	134.7	68.93	.2228	112.2	68.92	.2198	96.15	68.92	.2172	84.12	68.92	.2150
— 70	138.2	70.18	.2260	115.2	70.17	.2230	98.69	70.17	.2205	86.34	70.17	.2183
— 60	141.8	71.44	.2292	118.1	71.43	.2262	101.2	71.43	.2237	88.57	71.43	.2215
— 50	145.3	72.71	.2323	121.1	72.71	.2293	103.8	72.71	.2268	90.79	72.70	.2246
— 40	148.9	74.00	0.2354	124.1	74.00	0.2324	106.3	73.99	0.2299	93.01	73.99	0.2277
— 30	152.4	75.30	.2385	127.0	75.30	.2355	108.9	75.30	.2330	95.24	75.29	.2308
— 20	156.0	76.61	.2415	130.0	76.61	.2385	111.4	76.61	.2360	97.46	76.61	.2338
— 10	159.5	77.94	.2445	132.9	77.94	.2415	113.9	77.94	.2390	99.68	77.93	.2368
0	163.1	79.28	.2475	135.9	79.28	.2445	116.5	79.28	.2419	101.9	79.28	.2397
10	166.6	80.64	0.2504	138.9	80.64	0.2474	119.0	80.63	0.2449	104.1	80.63	0.2427
20	170.2	82.00	.2533	141.8	82.00	.2503	121.6	82.00	.2477	106.4	82.00	.2455
30	173.8	83.38	.2561	144.8	83.38	.2531	124.1	83.38	.2506	108.6	83.38	.2484
40	177.3	84.78	.2589	147.7	84.78	.2559	126.6	84.78	.2534	110.8	84.77	.2512
50	180.9	86.19	.2617	150.7	86.18	.2587	129.2	86.18	.2562	113.0	86.18	.2540
60	184.4	87.61	0.2645	153.7	87.61	0.2615	131.7	87.60	0.2590	115.2	87.60	0.2568
70	188.0	89.04	.2672	156.6	89.04	.2642	134.2	89.04	.2617	117.5	89.04	.2595
80	191.5	90.49	.2699	159.6	90.49	.2669	136.8	90.48	.2644	119.7	90.48	.2622
90	195.1	91.95	.2726	162.6	91.95	.2696	139.3	91.95	.2671	121.9	91.94	.2649
100	198.6	93.42	.2753	165.5	93.42	.2723	141.9	93.42	.2697	124.1	93.42	.2675
110	202.2	94.91	0.2779	168.5	94.91	0.2749	144.4	94.91	0.2724	126.3	94.91	0.2702
120	205.7	96.41	.2805	171.4	96.41	.2775	146.9	96.41	.2750	128.6	96.41	.2728
130	209.3	97.92	.2831	174.4	97.92	.2801	149.5	97.92	.2776	130.8	97.92	.2754
140	212.8	99.45	.2857	177.4	99.45	.2827	152.0	99.45	.2801	133.0	99.45	.2779
150	216.4	100.99	.2882	180.3	100.99	.2852	154.6	100.99	.2827	135.2	100.99	.2805
160	219.9	102.55	0.2908	183.3	102.54	0.2878	157.1	102.54	0.2852	137.5	102.54	0.2830
170	——	———	———	186.2	104.11	.2903	159.6	104.11	.2877	139.7	104.11	.2855

TABLE 2A–13. PROPERTIES OF SUPERHEATED VAPOR, FREON 12 (*Continued*)

Temp. °F.	Abs. Pressure 0.45 lbs./in.² Gage Pressure 29.00 ins. vac. (Sat'n. Temp. −128.2°F.)			Abs. Pressure 0.50 lbs./in.² Gage Pressure 28.90 ins. vac. (Sat'n. Temp. −125.8°F.)			Abs. Pressure 0.55 lbs./in.² Gage Pressure 28.80 ins. vac. (Sat'n. Temp. −123.6°F.)			Abs. Pressure 0.60 lbs./in.² Gage Pressure 28.70 ins. vac. (Sat'n. Temp. −121.7°F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(at sat'n)	(65.23)	(63.09)	(0.1968)	(59.12)	(63.37)	(0.1959)	(54.09)	(63.62)	(0.1951)	(49.85)	(63.85)	(0.1943)
−120	66.85	64.05	0.1996	60.15	64.05	0.1978	54.67	64.05	0.1963	50.11	64.04	0.1948
−110	68.83	65.25	.2030	61.93	65.25	.2013	56.29	65.25	.1997	51.59	65.24	.1983
−100	70.81	66.46	0.2064	63.72	66.46	0.2047	57.91	66.45	0.2031	53.08	66.45	0.2017
− 90	72.79	67.68	.2098	65.50	67.68	.2080	59.53	67.68	.2065	54.56	67.67	.2050
− 80	74.76	68.92	.2131	67.28	68.91	.2113	61.15	68.91	.2098	56.05	68.91	.2083
− 70	76.74	70.16	.2163	69.06	70.16	.2146	62.77	70.16	.2130	57.53	70.16	.2116
− 60	78.72	71.43	.2195	70.84	71.42	.2178	64.39	71.42	.2162	59.01	71.42	.2148
− 50	80.69	72.70	0.2227	72.62	72.70	0.2209	66.01	72.70	0.2194	60.50	72.69	0.2179
− 40	82.67	73.99	.2258	74.39	73.99	.2240	67.62	73.98	.2225	61.98	73.98	.2210
− 30	84.65	75.29	.2288	76.17	75.29	.2271	69.24	75.29	.2255	63.46	75.28	.2241
− 20	86.62	76.60	.2319	77.95	76.60	.2301	70.86	76.60	.2286	64.95	76.60	.2271
− 10	88.60	77.93	.2349	79.73	77.93	.2331	72.48	77.93	.2316	66.43	77.93	.2301
0	90.57	79.27	0.2378	81.51	79.27	0.2361	74.09	79.27	0.2345	67.91	79.27	0.2331
10	92.55	80.63	.2407	83.29	80.63	.2390	75.71	80.62	.2374	69.39	80.62	.2360
20	94.53	82.00	.2436	85.07	81.99	.2419	77.33	81.99	.2403	70.88	81.99	.2389
30	96.50	83.38	.2465	86.85	83.37	.2447	78.95	83.37	.2431	72.36	83.37	.2417
40	98.48	84.77	.2493	88.62	84.77	.2475	80.56	84.77	.2460	73.84	84.77	.2445
50	100.5	86.18	0.2521	90.40	86.18	0.2503	82.18	86.18	0.2488	75.33	86.17	0.2473
60	102.4	87.60	.2548	92.18	87.60	.2531	83.79	87.60	.2515	76.81	87.59	.2501
70	104.4	89.03	.2576	93.96	89.03	.2558	85.41	89.03	.2543	78.29	89.03	.2528
80	106.4	90.48	.2603	95.73	90.48	.2585	87.03	90.48	.2570	79.77	90.48	.2555
90	108.4	91.94	.2629	97.51	91.94	.2612	88.64	91.94	.2596	81.25	91.94	.2582
100	110.3	93.42	0.2656	99.29	93.41	0.2639	90.26	93.41	0.2623	82.73	93.41	0.2609
110	112.3	94.90	.2682	101.1	94.90	.2665	91.88	94.90	.2649	84.22	94.90	.2635
120	114.3	96.40	.2709	102.8	96.40	.2691	93.49	96.40	.2676	85.70	96.40	.2661
130	116.3	97.92	.2734	104.6	97.92	.2717	95.11	97.92	.2701	87.18	97.91	.2687
140	118.2	99.45	.2760	106.4	99.44	.2743	96.72	99.44	.2727	88.66	99.44	.2713
150	120.2	100.99	0.2786	108.2	100.98	0.2768	98.34	100.98	0.2753	90.14	100.98	0.2738
160	122.2	102.54	.2811	110.0	102.54	.2794	99.95	102.54	.2778	91.62	102.54	.2764
170	124.2	104.11	.2836	111.7	104.10	.2819	101.6	104.10	.2803	93.10	104.10	.2789
180	126.1	105.69	.2861	113.5	105.68	.2844	103.2	105.68	.2828	94.59	105.68	.2814

Temp. °F.	Abs. Pressure 0.65 lbs./in.^{2} Gage Pressure 28.60 ins. vac. (Sat'n. Temp. −119.7°F.)			Abs. Pressure 0.70 lbs. /in.^{2} Gage Pressure 28.50 ins. vac. (Sat'n. Temp. −118.1°F.)			Abs. Pressure 0.75 lbs./in.^{2} Gage Pressure 28.39 ins. vac. (Sat'n. Temp. −116.4°F.)			Abs. Pressure 0.80 lbs./in.^{2} Gage Pressure 28.29 ins. vac. (Sat'n. Temp. −114.8°F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(at sat'n)	(46.28)	(64.07)	(0.1936)	(43.17)	(64.27)	(0.1930)	(40.49)	(64.46)	(0.1924)	(38.13)	(64.66)	(0.1919)
−110	47.61	65.24	0.1970	44.20	65.24	0.1957	41.25	65.23	0.1946	38.66	65.23	0.1935
−100	48.99	66.45	0.2004	45.48	66.44	0.1991	42.44	66.44	0.1980	39.78	66.44	0.1969
− 90	50.36	67.67	.2037	46.75	67.67	.2025	43.63	67.66	.2014	40.89	67.66	.2003
− 80	51.73	68.90	.2070	48.03	68.90	.2058	44.82	68.90	.2047	42.01	68.90	.2036
− 70	53.10	70.15	.2103	49.30	70.15	.2090	46.01	70.15	.2079	43.12	70.14	.2068
− 60	54.47	71.42	.2135	50.57	71.41	.2122	47.19	71.41	.2111	44.24	71.41	.2100
− 50	55.84	72.69	0.2166	51.84	72.69	0.2154	48.38	72.69	0.2143	45.35	72.68	0.2132
− 40	57.21	73.98	.2197	53.12	73.98	.2185	49.57	73.97	.2174	46.47	73.97	.2163
− 30	58.58	75.28	.2228	54.39	75.28	.2216	50.76	75.28	.2204	47.58	75.27	.2194
− 20	59.95	76.60	.2258	55.66	76.59	.2246	51.94	76.59	.2234	48.69	76.59	.2224
− 10	61.32	77.92	.2288	56.93	77.92	.2276	53.13	77.92	.2264	49.81	77.92	.2254
0	62.68	79.27	0.2317	58.20	79.26	0.2305	54.32	79.26	0.2294	50.92	79.26	0.2283
10	64.05	80.62	.2347	59.47	80.62	.2334	55.50	80.62	.2323	52.03	80.61	.2312
20	65.42	81.99	.2376	60.74	81.99	.2363	56.69	81.98	.2352	53.14	81.98	.2341
30	66.79	83.37	.2404	62.02	83.37	.2392	57.88	83.36	.2380	54.26	83.36	.2370
40	68.16	84.76	.2432	63.29	84.76	.2420	59.06	84.76	.2409	55.37	84.76	.2398
50	69.53	86.17	0.2460	64.56	86.17	0.2448	60.25	86.17	0.2437	56.48	86.17	0.2426
60	70.90	87.59	.2488	65.83	87.59	.2476	61.44	87.59	.2464	57.59	87.59	.2454
70	72.26	89.03	.2515	67.10	89.03	.2503	62.62	89.02	.2492	58.71	89.02	.2481
80	73.63	90.47	.2542	68.37	90.47	.2530	63.81	90.47	.2519	59.82	90.47	.2508
90	75.00	91.94	.2569	69.64	91.93	.2557	64.99	91.93	.2545	60.94	91.93	.2535
100	76.37	93.41	0.2596	70.91	93.41	0.2583	66.18	93.41	0.2572	62.04	93.40	0.2561
110	77.74	94.90	.2622	72.18	94.90	.2610	67.37	94.89	.2598	63.15	94.89	.2588
120	79.10	96.40	.2648	73.45	96.40	.2636	68.55	96.39	.2624	64.27	96.39	.2614
130	80.47	97.91	.2674	74.72	97.91	.2662	69.74	97.91	.2650	65.38	97.91	.2640
140	81.84	99.44	.2700	75.99	99.44	.2687	70.92	99.44	.2676	66.49	99.44	.2665
150	83.21	100.98	0.2725	77.26	100.98	0.2713	72.11	100.98	0.2702	67.60	100.98	0.2691
160	84.57	102.53	.2750	78.53	102.53	.2738	73.29	102.53	.2727	68.71	102.53	.2716
170	85.94	104.10	.2776	79.80	104.10	.2763	74.48	104.10	.2751	69.82	104.10	.2741
180	87.31	105.68	.2800	81.07	105.68	.2788	75.66	105.68	.2777	70.93	105.68	.2766
190	88.67	107.27	.2825	82.34	107.27	.2813	76.85	107.27	.2802	72.04	107.27	.2791

TABLE 2A-13. PROPERTIES OF SUPERHEATED VAPOR, FREON 12 (*Continued*)

Temp. °F.	Abs. Pressure 0.90 lbs./in.² Gage Pressure 28.09 ins. vac. (Sat'n. Temp. −112.0°F.)			Abs. Pressure 1.00 lbs./in.² Gage Pressure 27.88 ins. vac. (Sat'n. Temp. −109.3°F.)			Abs. Pressure 1.20 lbs./in.² Gage Pressure 27.48 ins. vac. (Sat'n. Temp. −104.6°F.)			Abs. Pressure 1.40 lbs./in.² Gage Pressure 27.07 ins. vac. (Sat'n. Temp. −100.6°F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(at sat'n)	(34.16)	(64.99)	(0.1909)	(30.97)	(65.30)	(0.1901)	(26.14)	(65.85)	(0.1887)	(22.64)	(66.33)	(0.1875)
−110	34.36	65.22	0.1916	....	....	....	....	....	....	....	....	....
−100	35.35	66.43	.1950	31.80	66.43	0.1933	26.48	66.41	0.1902	22.68	66.40	0.1877
− 90	36.34	67.66	.1983	32.69	67.65	.1966	27.23	67.64	.1936	23.32	67.63	.1910
− 80	37.33	68.89	.2016	33.59	68.89	.1999	27.97	68.87	.1969	23.96	68.86	.1943
− 70	38.32	70.14	.2049	34.48	70.13	.2032	28.72	70.12	.2001	24.60	70.11	.1976
− 60	39.31	71.40	.2081	35.37	71.40	.2064	29.46	71.39	.2033	25.24	71.38	.2008
− 50	40.30	72.68	0.2112	36.26	72.67	0.2095	30.21	72.66	0.2065	25.88	72.65	0.2039
−40	41.29	73.97	.2143	37.16	73.96	.2126	30.95	73.95	.2096	26.52	73.94	.2070
− 30	42.28	75.27	.2174	38.05	75.26	.2157	31.69	75.25	.2127	27.15	75.24	.2101
− 20	43.27	76.58	.2204	38.94	76.58	.2187	32.44	76.57	.2157	27.79	76.56	.2131
− 10	44.26	77.91	.2234	39.83	77.91	.2217	33.18	77.90	.2187	28.43	77.89	.2161
0	45.25	79.25	0.2264	40.72	79.25	0.2246	33.92	79.24	0.2216	29.07	79.23	0.2191
10	46.24	80.61	.2293	41.61	80.61	.2276	34.67	80.60	.2246	29.70	80.59	.2220
20	47.23	81.98	.2322	42.50	81.97	.2305	35.41	81.97	.2274	30.34	81.96	.2249
30	48.22	83.36	.2350	43.39	83.35	.2333	36.15	83.35	.2303	30.98	83.34	.2278
40	49.21	84.75	.2379	44.28	84.75	.2361	36.89	84.74	.2331	31.61	84.73	.2306
50	50.20	86.16	0.2407	45.17	86.16	0.2389	37.64	86.15	0.2359	32.25	86.14	0.2334
60	51.19	87.58	.2434	46.06	87.58	.2417	38.38	87.57	.2387	32.89	87.56	.2361
70	52.18	89.02	.2462	46.95	89,01	.2444	39.12	89.01	.2414	33.53	89.00	.2389
80	53.17	90.47	.2489	47.85	90.46	.2471	39.86	90.46	.2441	34.16	90.45	.2416
90	54.15	91.93	.2515	48.74	91.92	.2498	40.61	91.92	.2468	34.80	91.91	.2443
100	55.14	93.40	0.2542	49.63	93.40	0.2525	41.35	93.39	0.2495	35.44	93.39	0.2469
110	56.13	94.89	.2568	50.52	94.89	.2551	42.09	94.88	.2521	36.07	94.87	.2496
120	57.12	96.39	.2594	51.41	96.39	.2577	42.83	96.38	.2547	36.71	96.37	.2522
130	58.11	97.90	.2620	52.29	97.90	.2603	43.57	97.90	.2573	37.34	97.89	.2548
140	59.10	99.43	.2646	53.18	99.43	.2629	44.31	99.42	.2599	37.98	99.42	.2573
150	60.08	100.97	0.2672	54.07	100.97	0.2654	45.06	100.96	0.2624	38.62	100.96	0.2599
160	61.07	102.53	.2697	54.96	102.52	.2680	45.80	102.52	.2650	39.25	102.51	.2624
170	62.06	104.09	.2722	55.85	104.09	.2705	46.54	104.09	.2675	39.89	104.08	.2649
180	63.05	105.67	.2747	56.74	105.67	.2730	47.28	105.67	.2700	40.52	105.66	.2674
190	64.04	107.27	.2772	57.63	107.27	.2754	48.02	107.26	.2724	41.16	107.26	.2699
200	......	......	......	58.52	108.87	0.2779	48.76	108.87	0.2749	41.79	108.86	0.2723

Temp. °F.	Abs. Pressure 1.60 lbs. /in.² Gage Pressure 26.66 ins. vac. (Sat'n. Temp. −97.1°F.)			Abs. Pressure 1.80 lbs /in.² Gage Pressure 26.26 ins. vac. (Sat'n. Temp. −93.8°F.)			Abs. Pressure 2.0 lbs./in.² Gage Pressure 25.85 ins. vac. (Sat'n. Temp. −90.8°F.)			Abs. Pressure 2.5 lbs./in.² Gage Pressure 24.83 ins. vac. (Sat'n. Temp. −84.3°F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(at sat'n)	(20.00)	(66.75)	(0.1865)	(17.93)	(67.14)	(0.1857)	(16.26)	(66.49)	(0.1849)	(13.22)	(68.26)	(0.1833)
− 90	20.39	67.62	0.1888	18.11	67.60	0.1869	16.29	67.59	0.1851	....	....	....
− 80	20.95	68.85	.1921	18.61	68.84	.1902	16.74	68.83	.1884	13.37	68.80	0.1847
− 70	21.51	70.10	.1954	19.11	70.09	.1934	17.19	70.08	.1917	13.73	70.05	.1880
− 60	22.07	71.37	.1986	19.61	71.36	.1966	17.64	71.35	.1949	14.09	71.32	.1912
− 50	22.63	72.64	0.2017	20.11	72.63	0.1998	18.09	72.62	0.1980	14.45	72.60	0.1943
− 40	23.19	73.93	.2048	20.60	73.92	.2029	18.54	73.91	.2011	14.81	73.89	.1974
− 30	23.75	75.23	.2079	21.10	75.22	.2060	18.98	75.22	.2042	15.17	75.19	.2005
− 20	24.31	76.55	.2109	21.60	76.54	.2090	19.43	76.53	.2072	15.53	76.51	.2035
− 10	24.87	77.88	.2139	22.10	77.87	.2120	19.88	77.86	.2102	15.89	77.84	.2065
0	25.44	79.22	0.2169	22.59	79.21	0.2149	20.33	79.21	0.2132	16.25	79.18	0.2095
10	25.98	80.58	.2198	23.09	80.57	.2179	20.77	80.56	.2161	16.61	80.54	.2124
20	26.54	81.95	.2227	23.59	81.94	.2208	21.22	81.93	.2190	16.96	81.91	.2153
30	27.10	83.33	.2256	24.08	83.32	.2236	21.67	83.31	.2219	17.32	83.29	.2182
40	27.66	84.73	.2284	24.58	84.72	.2264	22.11	84.71	.2247	17.68	84.69	.2210
50	28.21	86.14	0.2312	25.07	86.13	0.2292	22.56	86.12	0.2275	18.04	86.10	0.2238
60	28.77	87.56	.2339	25.57	87.55	.2320	23.01	87.54	.2302	18.40	87.52	.2265
70	29.33	88.99	.2367	26.06	88.99	.2347	23.45	88.98	.2330	18.75	88.96	.2293
80	29.89	90.44	.2394	26.56	90.43	.2374	23.90	90.43	.2357	19.11	90.41	.2320
90	30.44	91.90	.2421	27.06	91.90	.2401	24.35	91.89	.2384	19.47	91.87	.2347
100	31.00	93.38	0.2447	27.55	93.37	0.2428	24.79	93.37	0.2410	19.83	93.35	0.2373
110	31.56	94.87	.2474	28.05	94.86	.2454	25.24	94.85	.2437	20.18	94.84	.2400
120	32.11	96.37	.2500	28.54	96.36	.2480	25.68	96.36	.2463	20.54	96.34	.2426
130	32.67	97.88	.2526	29.04	97.88	.2506	26.13	97.87	.2489	20.90	97.86	.2452
140	33.23	99.41	.2551	29.53	99.41	.2532	26.58	99.40	.2514	21.25	99.39	.2478
150	33.78	100.95	0.2577	30.03	100.95	0.2557	27.02	100.94	0.2540	21.61	100.93	0.2503
160	34.34	102.51	.2602	30.52	102.50	.2583	27.47	102.50	.2565	21.97	102.48	.2528
170	34.90	104.07	.2627	31.02	104.07	.2608	27.91	104.06	.2590	22.33	104.05	.2554
180	35.45	105.66	.2652	31.51	105.65	.2633	28.36	105.65	.2615	22.68	105.63	.2578
190	36.01	107.25	.2677	32.01	107.25	.2657	28.80	107.24	.2640	23.04	107.23	.2603
200	36.57	108.86	0.2701	32.50	108.85	0.2682	29.25	108.85	0.2665	23.40	108.84	0.2628
210	37.12	110.48	.2726	33.00	110.47	.2706	29.70	110.47	.2689	23.75	110.46	.2652
220	....	....	....	....	....	....	....	....	....	24.11	112.09	.2676

TABLE 2A-13. PROPERTIES OF SUPERHEATED VAPOR, FREON 12 (*Continued*)

Temp. °F.	Abs. Pressure 3.0 lbs./in.² Gage Pressure 23.81 ins. vac. (Sat'n. Temp. −78.9°F.)			Abs. Pressure 3.5 lbs./in.² Gage Pressure 22.80 ins. vac. (Sat'n. Temp. −74.1°F.)			Abs. Pressure 4.0 lbs./in.² Gage Pressure 21.78 ins. vac. (Sat'n. Temp. −69.8°F.)			Abs. Pressure 4.5 lbs./in.² Gage Pressure 20.76 ins. vac. (Sat'n. Temp. −66.0°F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(at sat'n)	(11.16)	(68.90)	(0.1821)	(9.674)	(69.47)	(0.1810)	(8.549)	(69.97)	(0.1832)	(7.665)	(70.42)	(0.1795)
— 70	11.43	70.00	0.1849	9.780	69.98	0.1824	....	....	....	....	....	....
— 60	11.73	71.27	.1881	10.04	71.25	.1856	8.772	71.21	0.1833	7.787	71.19	0.1813
— 50	12.03	72.55	0.1913	10.30	72.53	0.1887	8.999	72.49	0.1865	7.989	72.46	0.1845
— 40	12.33	73.84	.1944	10.56	73.82	.1918	9.225	73.78	.1896	8.190	73.76	.1876
— 30	12.63	75.15	.1975	10.81	75.12	.1949	9.451	75.09	.1927	8.392	75.07	.1907
— 20	12.93	76.47	.2005	11.07	76.44	.1979	9.677	76.41	.1957	8.593	76.39	.1937
— 10	13.23	77.80	.2035	11.33	77.77	.2009	9.903	77.75	.1987	8.794	77.72	.1967
0	13.53	79.15	0.2065	11.59	79.12	0.2039	10.13	79.10	0.2017	8.995	79.07	0.1997
10	13.83	80.51	.2094	11.84	80.48	.2068	10.35	80.46	.2046	9.196	80.43	.2026
20	14.13	81.88	.2123	12.10	81.85	.2097	10.58	81.83	.2075	9.396	81.80	.2055
30	14.43	83.26	.2151	12.36	83.23	.2126	10.80	83.21	.2104	9.597	83.18	.2084
40	14.72	84.66	.2180	12.61	84.63	.2154	11.03	84.61	.2132	9.797	84.58	.2112
50	15.02	86.07	0.2208	12.87	86.05	0.2182	11.25	86.03	0.2160	9.997	86.00	0.2140
60	15.32	87.50	.2235	13.13	87.48	.2210	11.48	87.45	.2187	10.20	87.43	.2168
70	15.62	88.93	.2263	13.38	88.92	.2237	11.70	88.89	.2215	10.40	88.87	.2195
80	15.92	90.38	.2290	13.64	90.37	.2264	11.93	90.35	.2242	10.60	90.32	.2222
90	16.22	91.85	.2317	13.89	91.83	.2291	12.15	91.81	.2269	10.80	91.79	.2249
100	16.52	93.32	0.2343	14.15	93.31	0.2318	12.38	93.29	0.2296	11.00	93.27	0.2276
110	16.81	94.81	.2370	14.41	94.80	.2344	12.60	94.78	.2322	11.20	94.76	.2302
120	17.11	96.32	.2396	14.66	96.30	.2370	12.82	96.28	.2348	11.40	96.26	.2329
130	17.41	97.83	.2422	14.92	97.82	.2396	13.05	97.80	.2374	11.60	97.78	.2355
140	17.71	99.36	.2448	15.17	99.35	.2422	13.27	99.33	.2400	11.79	99.31	.2380
150	18.01	100.90	0.2473	15.43	100.89	0.2448	13.50	100.88	0.2425	11.99	100.85	0.2406
160	18.30	102.46	.2498	15.68	102.45	.2473	13.72	102.43	.2451	12.19	102.41	.2431
170	18.60	104.04	.2523	15.94	104.01	.2498	13.94	104.00	.2476	12.39	103.98	.2456
180	18.90	105.62	.2548	16.20	105.60	.2523	14.17	105.58	.2501	12.59	105.56	.2481
190	19.20	107.21	.2573	16.45	107.19	.2548	14.39	107.18	.2526	12.79	107.16	.2506
200	19.49	108.82	0.2598	16.71	108.80	0.2572	14.62	108.79	0.2550	12.99	108.77	0.2531
210	19.79	110.45	.2622	16.96	110.42	.2597	14.84	110.41	.2575	13.19	110.39	.2555
220	20.09	112.08	.2646	17.22	112.06	.2621	15.06	112.05	.2599	13.39	112.02	.2579
230	20.39	113.73	.2670	17.47	113.71	.2645	15.29	113.70	.2623	13.59	113.67	.2603
240	....	....	....	....	....	....	15.51	115.36	.2647	13.78	115.34	.2627

Temp. °F.	Abs. Pressure 5.0 lbs./in.^{2} Gage Pressure 19.74 ins. vac. (Sat'n. Temp. −62.5°F.)			Abs. Pressure 5.5 lbs./in.^{2} Gage Pressure 18.73 ins. vac. (Sat'n. Temp. −59.2°F.)			Abs. Pressure 6.0 lbs./in.^{2} Gage Pressure 17.71 ins. vac. (Sat'n. Temp. −56.2°F.)			Abs. Pressure 6.5 lbs./in.^{2} Gage Pressure 16.69 ins. vac. (Sat'n. Temp. −53.4°F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(at sat'n)	(6.953)	(70.83)	(0.1788)	(6.367)	(71.22)	(0.1782)	(5.874)	(71.58)	(0.1776)	(5.455)	(71.91)	(0.1772)
− 60	6.998	71.15	0.1796	....	....	....	....	....	....	....	....	....
− 50	7.180	72.43	.1827	6.519	72.39	0.1811	5.968	72.37	0.1796	5.502	72.35	0.1782
− 40	7.363	73.72	.1859	6.685	73.69	.1843	6.121	73.67	.1827	5.644	73.64	.1814
− 30	7.544	75.03	.1889	6.851	75.01	.1873	6.273	74.98	.1858	5.784	74.95	.1845
− 20	7.726	76.36	.1920	7.016	76.33	.1904	6.425	76.30	.1889	5.925	76.27	.1875
− 10	7.907	77.70	.1950	7.182	77.66	.1934	6.577	77.64	.1919	6.066	77.61	.1905
0	8.088	79.05	0.1979	7.347	79.02	0.1963	6.729	78.98	0.1948	6.206	78.96	0.1935
10	8.269	80.41	.2009	7.512	80.38	.1993	6.879	80.34	.1978	6.348	80.32	.1964
20	8.450	81.78	.2038	7.676	81.76	.2022	7.031	81.73	.2007	6.486	81.71	.1993
30	8.631	83.16	.2066	7.841	83.14	.2050	7.182	83.12	.2035	6.625	83.09	.2022
40	8.812	84.56	.2095	8.005	84.55	.2079	7.334	84.52	.2064	6.765	84.50	.2050
50	8.992	85.98	0.2123	8.170	85.96	0.2107	7.485	85.93	0.2092	6.905	85.92	0.2078
60	9.173	87.41	.2150	8.334	87.38	.2134	7.635	87.37	.2119	7.044	87.35	.2106
70	9.353	88.85	.2178	8.498	88.82	.2162	7.786	88.81	.2147	7.183	88.79	.2133
80	9.533	90.30	.2205	8.662	90.28	.2189	7.936	90.26	.2174	7.322	90.24	.2161
90	9.713	91.77	.2232	8.826	91.75	.2216	8.087	91.73	.2201	7.462	91.71	.2188
100	9.893	93.25	0.2258	8.990	93.23	0.2243	8.237	93.21	0.2228	7.601	93.19	0.2214
110	10.07	94.74	.2285	9.154	94.72	.2269	8.388	94.70	.2255	7.740	94.68	.2241
120	10.25	96.24	.2311	9.317	96.23	.2295	8.538	96.20	.2281	7.878	96.19	.2267
130	10.43	97.76	.2337	9.481	97.75	.2321	8.688	97.72	.2307	8.017	97.71	.2293
140	10.61	99.29	.2363	9.644	99.28	.2347	8.838	99.25	.2333	8.155	99.24	.2319
150	10.79	100.84	0.2388	9.808	100.82	0.2373	8.988	100.80	0.2358	8.294	100.78	0.2344
160	10.97	102.39	.2414	9.971	102.38	.2398	9.138	102.36	.2383	8.432	102.34	.2369
170	11.15	103.96	.2439	10.13	103.95	.2423	9.288	103.93	.2408	8.571	103.91	.2395
180	11.33	105.55	.2464	10.30	105.53	.2448	9.437	105.51	.2433	8.709	105.50	.2420
190	11.51	107.14	.2489	10.46	107.13	.2473	9.587	107.11	.2458	8.847	107.10	.2444
200	11.69	108.75	0.2513	10.62	108.74	0.2497	9.737	108.72	0.2483	8.986	108.71	0.2469
210	11.87	110.38	.2538	10.79	110.36	.2522	9.886	110.34	.2507	9.124	110.33	.2493
220	12.05	112.01	.2562	10.95	112.00	.2546	10.04	111.98	.2532	9.263	111.97	.2518
230	12.23	113.66	.2586	11.11	113.65	.2570	10.19	113.63	.2556	9.401	113.62	.2542
240	12.41	115.33	.2610	11.28	115.31	.2594	10.34	115.29	.2580	9.539	115.28	.2566
250	....	....	....	11.44	116.99	0.2618	10.48	116.97	0.2603	9.677	116.96	0.2590

TABLE 2A-13. PROPERTIES OF SUPERHEATED VAPOR, FREON 12 (*Continued*)

Temp. °F.	Abs. Pressure 7.0 lbs./in.² Gage Pressure 15.67 ins. vac. (Sat'n. Temp. −50.7°F.)			Abs. Pressure 7.5 lbs./in.² Gage Pressure 14.65 ins. vac. (Sat'n. Temp. −48.6°F.)			Abs. Pressure 8.0 lbs./in.² Gage Pressure 13.64 ins. vac. (Sat'n. Temp. −45.8°F.)			Abs. Pressure 10.0 lbs./in.² Gage Pressure 9.57 ins. vac. (Sat'n. Temp. −37.3°F.)			Abs. Pressure 11 lb./in.² Gage Pressure 7.5 in. vac. (Sat'n. Temp. −33.5°F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S	V	H	S
(at sat'n.)	(5.094)	(72.23)	(0.1768)	(4.774)	(72.47)	(0.1765)	(4.502)	(72.80)	(0.1760)	(3.662)	(73.82)	(0.1748)	(3.356)	(74.27)	(0.17432)
−50	5.103	72.33	0.1770	.....	......	......	.....	......	......	....	......	......	....	......	......
−40	5.234	73.62	.1801	4.879	73.60	0.1791	4.569	73.56	0.1778	.....	......	......	.....	......	....
−30	5.365	74.92	.1832	5.002	74.90	.1820	4.684	74.87	.1809	3.728	74.77	0.1770	3.383	74.73	0.17540
−20	5.496	76.25	.1863	5.125	76.23	.1850	4.799	76.20	.1839	3.821	76.11	.1801	3.467	76.06	.17845
−10	5.627	77.59	.1893	5.247	77.56	.1880	4.914	77.54	.1869	3.913	77.46	.1831	3.551	77.40	.18146
0	5.757	78.94	0.1922	5.368	78.92	0.1910	5.028	78.89	0.1899	4.006	78.81	0.1861	3.635	78.75	0 18448
10	5.888	80.31	.1952	5.490	80.28	.1940	5.142	80.26	.1928	4.098	80.18	.1891	3.719	80.12	.18742
20	6.018	81.69	.1981	5.612	81.67	.1969	5.257	81.64	.1957	4.189	81.56	.1919	3.802	81.50	.19032
30	6.147	83.07	.2009	5.733	83.06	.1997	5.370	83.02	.1986	4.280	82.94	.1948	3.887	82.90	.19320
40	6.277	84.48	.2038	5.854	84.46	.2026	5.484	84.43	.2014	4.371	84.35	.1977	3.971	84.31	.19605
50	6.407	85.90	0.2066	5.976	85.88	0.2054	5.598	85.85	0.2043	4.463	85.77	.2005	4.055	85.73	0 19887
60	6.537	87.32	.2093	6.097	87.30	.2081	5.711	87.27	.2070	4.556	87.19	.2033	4.138	87 16	.20165
70	6.666	88.77	.2121	6.218	88.75	.2109	5.824	88.72	.2098	4.648	88.64	.2060	4.221	88.61	.20440
80	6.796	90.22	.2148	6.339	90.20	.2136	5.938	90.18	.2125	4.740	90.11	.2087	4.304	90.07	.20713
90	6.925	91.69	.2175	6.459	91.68	.2163	6.051	91.64	.2152	4.832	91.58	.2114	4.388	91.54	.20984
100	7.054	93.17	0.2202	6.581	93.15	0.2190	6.165	93.13	0.2179	4.923	93.05	0.2141	4.471	93.03	0.21251
110	7.183	94.67	.2228	6.702	94.65	.2216	6.278	94.63	.2205	5.015	94.56	.2168	4.553	94.52	.21515
120	7.313	96.17	.2255	6.822	96.15	.2243	6.391	96.13	.2231	5.107	96.07	.2194	4.636	96.03	.21778
130	7.441	97.69	.2281	6.942	97.68	.2269	6.504	97 64	.2257	5.198	97.59	.2220	4.718	97.56	.22037
140	7.570	99.22	.2306	7.062	99.20	.2294	6.617	99.18	.2283	5.289	99.14	.2246	4.800	99.09	.22296
150	7.699	100.77	0.2332	7.182	100.76	0.2320	6.730	100.73	0.2309	5.379	100.66	0.2271	4.882	100 63	0.22551
160	7.828	102.33	.2357	7.303	102.31	.2345	6.843	102.29	.2334	5.470	102.24	.2297	4.965	102.20	.22805
170	7.956	103.90	.2382	7.423	103.89	.2370	6.955	103.87	.2359	5.560	103.81	.2322	5.047	103.78	.23057
180	8.085	105.48	.2407	7.543	105.47	.2395	7.068	105.44	.2384	5.650	105.40	.2347	5.130	105.37	.23308
190	8.213	107.08	.2432	7.663	107.07	.2420	7.181	107.05	.2409	5.740	107.00	.2372	5.214	106.97	.23557
200	8.342	108.79	0.2457	7.783	108.68	0.2445	7.294	108.67	0.2434	5.831	108.63	0.2396	5.297	108.58	0.23804
210	8.471	110.32	.2481	7.904	110.31	.2469	7.407	110.28	.2458	5.921	110.25	.2421	5.379	110.21	.24049
220	8.599	111.96	.2505	8.024	111.94	.2493	7.520	111.93	.2483	6.011	111.88	.2445	5.462	111.85	.24291
230	8.728	113.61	.2530	8.144	113.60	.2518	7.633	113.57	.2507	6.101	113.53	.2469	5.544	113.50	.24532
240	8.856	115.27	.2554	8.264	115.26	.2542	7.746	115.23	.2531	6.191	115.20	.2493	5.626	115.18	.24773
250	8.985	116.97	0.2577	8.385	116.94	0.2565	7.859	116.91	0.2555	6.281	116.88	0.2517	.....	......	....
260	.....	......	......	8.504	118.63	.2589	7.972	118.60	.2579	6.371	118.58	.2541	.....	......	....
270	.....	......	......	.....	......	......	.....	......	......	6.461	120.30	.2564	.....	......	....

Temp. °F.	Abs. Pressure 12 lb./in.² Gage Pressure 5.5 in vac. (Sat'n. Temp.—30.0° F.)			Abs. Pressure 13 lb./in.² Gage Pressure 3.5 in. vac. (Sat'n. Temp.—26.8° F.)			Abs. Pressure 14 lb./in.² Gage Pressure 1.4 in. vac. (Sat'n. Temp.—23.7° F.)			Abs. Pressure 15 lb./in.² Gage Pressure 0.3 lb./in.² (Sat'n. Temp.—20.8° F.)		
(at sat'n)	*(3.093)*	*(74.69)*	*(0.17389)*	*(2.875)*	*(75.08)*	*(0.17350)*	*(2.677)*	*(75.45)*	*(0.17314)*	*(2.518)*	*(75.78)*	*(0.17282)*
−30	3.093	74.69	0.17389	......	....	....	......	....	....	......	....	....
−20	3.172	76.02	.17695	2.920	75.98	0.17556	2.706	75.94	0.17427	2.521	75.89	0.17307
−10	3.250	77.37	.17998	2.992	77.32	.17859	2.773	77.28	.17731	2.583	77.23	.17611
0	3.328	78.73	0.18299	3.064	78.69	0.18160	2.841	78.64	0.18032	2.646	78.59	0.17913
10	3.405	80.10	.18594	3.136	80.05	.18455	2.908	80.01	.18328	2.708	79.97	.18208
20	3.483	81.48	.18884	3.207	81.43	.18746	2.974	81.40	.18618	2.771	81.37	.18499
30	3.560	82.87	.19173	3.278	82.83	.19034	3.041	82.80	.18907	2.833	82.77	.18788
40	3.637	84.28	.19458	3.349	84.23	.19319	3.107	84.21	.19192	2.895	84.18	.19074
50	3.714	85.71	0.19739	3.420	85.66	0.19601	3.173	85.63	0.19475	2.957	85.60	0.19357
60	3.790	87.14	.20018	3.491	87.10	.19880	3.239	87.06	.19753	3.019	87.03	.19635
70	3.867	88.59	.20293	3.562	88.54	.20156	3.303	88.51	.20028	3.081	88.48	.19911
80	3.943	90.05	.20566	3.632	90.01	.20428	3.369	89.97	.20302	3.143	89.94	.20185
90	4.019	91.52	.20836	3.703	91.48	.20699	3.435	91.44	.20572	3.204	91.41	.20455
100	4 095	93.00	0.21104	3.774	92.96	0.20967	3.501	92.93	0.20841	3.266	92.91	0.20723
110	4.170	94.50	.21367	3.844	94.47	.21231	3.567	94.43	.21106	3.327	94.41	.20989
120	4.246	96.01	.21631	3.915	95.98	.21495	3.633	95.95	.21369	3.388	95.91	.21252
130	4.323	97.53	.21891	3.986	97.50	.21755	3.699	97.48	.21630	3.450	97.44	.21513
140	4.400	99.07	.22151	4.056	99.04	.22014	3.763	99.01	.21889	3.510	98.98	.21772
150	4.474	100.62	0.22406	4.126	100.59	0.22270	3.828	100.56	0.22144	3.571	100.53	0.22028
160	4.549	102.18	.22659	4.196	102.16	.22524	3.894	102.13	.22400	3.632	102.10	.22282
170	4.624	103.75	.22911	4.266	103.73	.22775	3.960	103.71	.22651	3.694	103.68	.22535
180	4.700	105.34	.23162	4.337	105.32	.23027	4.025	105.30	.22902	3.755	105.27	.22786
190	4.774	106.94	.23409	4.408	106.92	.23276	4.090	106.90	.23150	3.816	106.87	.23034
200	4.850	108.55	0.23656	4.478	108.55	0.23523	4.155	108.52	0.23398	3.877	108.49	0.23282
210	4.926	110.18	.23901	4.547	110.16	.23767	4.220	110.14	.23643	3.938	110.12	.23527
220	5.000	111.82	.24144	4.617	111.81	.24011	4.285	111.78	.23886	3.998	111.77	.23770
230	5.076	113.47	.24385	4.686	113.45	.24252	4.350	113.44	.24128	4.059	113.42	.24011
240	5.152	115.15	.24626	4.755	115.13	.24492	4.414	115.11	.24368	4.120	115.10	.24253
250	......	....	....	......	....	....	4.479	116.79	0.24607	4.181	116.78	0.24491

TABLE 2A-13. PROPERTIES OF SUPERHEATED VAPOR, FREON 12 (*Continued*)

Temp. °F.	Abs. Pressure 16 lb./in.² Gage Pressure 1.3 lb./in.² (Sat'n. Temp.—18.0° F.)			Abs. Pressure 17 lb./in.² Gage Pressure 2.3 lb./in.² (Sat'n. Temp.—15.4° F.)			Abs. Pressure 18 lb./in.² Gage Pressure 3.3 lb./in.² (Sat'n. Temp.—12.9° F.)			Abs. Pressure 19 lb./in.² Gage Pressure 4.3 lb./in.² (Sat'n. Temp.—10.5° F.)		
t	*V*	*H.*	*S*	*V*	*H*	*S*	*V*	*H*	*S*	*V*	*H*	*S*
(at sat'n)	*(2.370)*	*(76.11)*	*(0.17254)*	*(2.240)*	*(76.41)*	*(0.17226)*	*(2.123)*	*(76.70)*	*(0.17208)*	*(2.019)*	*(76.99)*	*(0.17180)*
−10	2.417	77.20	0.17498	2.268	77.15	0.17390	2.137	77.09	0.17289	2.022	77.05	0.17195
0	2.476	78.56	0.17800	2.325	78.52	0.17693	2.191	78.47	0.17592	2.072	78.42	0.17497
10	2.535	79.94	.18095	2.382	79.90	.17990	2.244	79.85	.17889	2.122	79.80	.17794
20	2.594	81.33	.18387	2.438	81.29	.18283	2.297	81.24	.18181	2.172	81.19	.18087
30	2.652	82.73	.18676	2.493	82.69	.18571	2.350	82.65	.18471	2.222	82.60	.18376
40	2.710	84.13	.18962	2.548	84.10	.18857	2.402	84.06	.18757	2.272	84.02	.18663
50	2.768	85.55	0.19244	2.603	85.52	0.19140	2.454	85.49	0.19041	2.321	85.45	0.18946
60	2.827	86.99	.19524	2.658	86.96	.19420	2.506	86.93	.19321	2.371	86.90	.19226
70	2.886	88.45	.19800	2.712	88.41	.19696	2.558	88.38	.19597	2.420	88.35	.19503
80	2.944	89.91	.20075	2.767	89.88	.19969	2.610	89.84	.19872	2.469	89.81	19777
90	3.002	91.39	.20345	2.822	91.36	.20241	2.662	91.32	.20142	2.518	91.29	.20047
100	3.059	92.88	0.20613	2.876	92.85	0.20510	2.713	92.81	0.20411	2.567	92.78	0.20317
110	3.117	94.38	.20879	2.930	94.35	.20774	2.764	94.32	.20676	2.616	94.28	.20583
120	3.175	95.89	.21143	2.984	95.86	.21038	2.815	95.83	.20941	2.665	95.80	.20847
130	3.232	97.42	.21403	3 038	97.39	.21298	2.867	97.36	.21201	2.714	97.33	.21108
140	3.290	98.95	.21662	3.092	98.93	.21558	2.918	98.90	.21462	2.763	98.88	.21368
150	3.347	100.50	0.21917	3.147	100.48	0.21814	2.969	100.45	0.21717	2.812	100.43	0.21625
160	3,404	102.07	.22172	3.201	102.05	.22070	3.020	102.02	.21971	2.861	102.00	.21880
170	3.461	103.65	.22425	3.256	103.63	.22323	3.072	103.60	.22223	2.910	103.59	.22133
180	3.519	105.24	.22677	3.310	105.22	.22574	3.124	105.19	.22477	2.958	105.18	.22384
190	3.576	106.85	.22925	3.364	106.82	.22822	3.175	106.80	.22725	3.006	106.78	.22633
200	3.633	108.47	0.23173	3.417	108.44	0.23070	3.226	108.42	0.22973	3.054	108.39	0.22880
210	3.690	110.10	.23418	3.470	110.07	.23315	3.277	110.05	.23219	3.102	110.02	.23126
220	3.747	111.74	.23662	3.524	111.71	.23558	3.327	111.69	.23461	3.150	111.66	.23369
230	3.803	113.40	.23903	3.578	113.37	.23800	3.378	113.34	.23703	3.198	113.31	.23612
240	3.860	115.07	.24143	3.632	115.04	.24041	3.428	115.00	.23944	3.246	114.99	.23852
250	3.917	116.76	0.24382	3.686	116.72	0.24279	3.478	116.68	0.24182	3.294	116.68	0.24091
260	......	....	....	3.739	118.41	.24517	3.528	118.36	.24420	3.342	118.37	.24327

Temp. °F.	Abs. Pressure 20 lb./in.² Gage Pressure 5.3 lb./in.² (Sat'n. Temp.—8.2° F.)			Abs. Pressure 22 lb./in.² Gage Pressure 7.3 lb./in.² (Sat'n. Temp.—3.8° F.)			Abs. Pressure 24 lb./in.² Gage Pressure 9.3 lb./in.² (Sat'n. Temp. 0.3° F.)			Abs. Pressure 26 lb./in.² Gage Pressure 11.3 lb./in.² (Sat'n. Temp. 4.1° F.)		
(at sat'n)	*(1.925)*	*(77.27)*	*(0.17160)*	*(1.762)*	*(77.77)*	*(0.17121)*	*(1.623)*	*(78.24)*	*(0.17089)*	*(1.510)*	*(78.68)*	*(0.17059)*
0	1.965	78.39	0.17407	1.779	78.30	0.17237	......	......	......	......	......	......
10	2.013	79.76	.17704	1.823	79.68	.17534	1.664	79.59	0.17378	1.530	79.50	0.17233
20	2.060	81.14	.17996	1.866	81.07	.17827	1.705	80.99	.17673	1.568	80.90	.17529
30	2.107	82.55	.18286	1.909	82.48	.18118	1.745	82.40	.17964	1.606	82.31	.17821
40	2.155	83.97	.18573	1.953	83.90	.18405	1.785	83.82	.18251	1.643	83.74	.18109
50	2.203	85.40	0.18858	1.997	85.33	0.18691	1.825	85.26	0.18536	1.680	85.19	0.18395
60	2.250	86.85	.19138	2.040	86.78	.18971	1.865	86.71	.18817	1.716	86.64	.18675
70	2.297	88.31	.19415	2.083	88.25	.19248	1.905	88.17	.19096	1.754	88.10	.18954
80	2.343	89.78	.19688	2.125	89.71	.19522	1.944	89.64	.19371	1.790	89.57	.19229
90	2.390	91.26	.19959	2.168	91.19	.19794	1.984	91.13	.19643	1.826	91.05	.19501
100	2.437	92.75	0.20229	2.211	92.68	0.20064	2.023	92.63	0.19912	1.863	92.55	0.19772
110	2.483	94.26	.20494	2.253	94.19	.20330	2.062	94.13	.20179	1.900	94.06	.20039
120	2.530	95.78	.20759	2.296	95.71	.20595	2.101	95.64	.20444	1.936	95.58	.20305
130	2.577	97.31	.21020	2.339	97.25	.20856	2.140	97.17	.20704	1.972	97.12	.20565
140	2.623	98.85	.21280	2.381	98.80	.21116	2.179	98.72	.20966	2.008	98.67	.20827
150	2.669	100.40	0.21537	2.423	100.35	0.21373	2.218	100.28	0.21223	2.045	100.23	0.21085
160	2.716	101.97	.21792	2.465	101.92	.21628	2.257	101.86	.21479	2.082	101.80	.21341
170	2.762	103.56	.22045	2.507	103.50	.21881	2.296	103.45	.21732	2.117	103.39	.21594
180	2.808	105.15	.22297	2.550	105.10	.22133	2.335	105.05	.21984	2.153	104.99	.21847
190	2.854	106.76	.22545	2.592	106.71	.22382	2.373	106.66	.22233	2.189	106.60	.22096
200	2.901	108.38	0.22794	2.634	108.33	0.22630	2.412	108.28	0.22481	2.224	108.23	0.22344
210	2.947	110.01	.23039	2.676	109.96	.22876	2.450	109.92	.22727	2.259	109.86	.22589
220	2.992	111.65	.23283	2.717	111.60	.23120	2.489	111.57	.22972	2.295	111.51	.22834
230	3.038	113.31	.23524	2.758	113.26	.23361	2.528	113.23	.23214	2.331	113.17	.23076
240	3.084	114.98	.23766	2.800	114.94	.23603	2.566	114.90	.23455	2.366	114.85	.23318
250	3.130	116.67	0.24005	2.842	116.62	0.23843	2.605	116.58	0.23695	2.402	116.54	0.23557
260	3.177	118.36	.24242	2.884	118.32	.24080	2.644	118.28	.23933	2.438	118.24	.23796
270	3.223	120.07	.24477	2.926	120.04	.24316	2.682	120.00	.24169	2.474	119.95	.24033
280	......	......	......	......	......	......	......	......	......	2.510	121.68	.24267

TABLE 2A-13. PROPERTIES OF SUPERHEATED VAPOR, FREON 12 (*Continued*)

Temp. °F.	Abs. Pressure 28 lb./in.² Gage Pressure 13.3 lb./in.² (Sat'n. Temp. 7.7° F.)			Abs. Pressure 30 lb./in.² Gage Pressure 15.3 lb./in.² (Sat'n. Temp. 11.1° F.)			Abs. Pressure 32 lb./in.² Gage Pressure 17.3 lb./in.² (Sat'n. Temp. 14.3° F.)			Abs. Pressure 34 lb./in.² Gage Pressure 19.3 lb./in.² (Sat'n. Temp. 17.4° F.)		
t	*V*	*H*	*S*	*V*	*H*	*S*	*V*	*H*	*S*	*V*	*H*	*S*
(at sat'n)	*(1.409)*	*(79.10)*	*(0.17032)*	*(1.323)*	*(79.47)*	*(0.17008)*	*(1.245)*	*(79.84)*	*(0.16985)*	*(1.175)*	*(80.20)*	*(0.16965)*
10	1.415	79.41	0.17099	......	......	......	......	......	......	......	......	......
20	1.450	80.81	.17393	1.350	80.73	0.17269	1.262	80.67	0.17152	1.183	80.58	0.17040
30	1.485	82.23	.17685	1.363	82.15	.17562	1.293	82.08	.17445	1.212	82.00	.17333
40	1.520	83.66	.17975	1.415	83.58	.17851	1.323	83.51	.17734	1.241	83.44	.17623
50	1.555	85.11	0.18261	1.448	85.03	0.18138	1.354	84.96	0.18022	1.270	84.88	0.17910
60	1.590	86.56	.18544	1.480	86.48	.18420	1.384	86.41	.18304	1.299	86.34	.18194
70	1.625	88.03	.18823	1.512	87.95	.18699	1.414	87.88	.18583	1.328	87.81	.18474
80	1.659	89.51	.19097	1.544	89.43	.18974	1.444	89.36	.18860	1.356	89.29	.18750
90	1.693	90.99	.19371	1.576	90.91	.19249	1.474	90.85	.19133	1.385	90.78	.19025
100	1.727	92.49	0.19642	1.608	92.41	0.19519	1.504	92.35	0.19404	1.413	92.29	0.19295
110	1.761	94.01	.19909	1.640	93.93	.19787	1.535	93.87	.19673	1.441	93.81	.19563
120	1.795	95.53	.20174	1.672	95.46	.20053	1.565	95.40	.19940	1.470	95.34	.19831
130	1.828	97.07	.20436	1.703	97.00	.20315	1.595	96.94	.20202	1.498	96.88	.20094
140	1.862	98.62	.20698	1.735	98.54	.20577	1.624	98.50	.20463	1.526	98.43	.20356
150	1.896	100.18	0.20956	1.767	100.11	0.20836	1.654	100.06	0.20721	1.554	100.00	0.20614
160	1.930	101.75	.21212	1.799	101.69	.21092	1.683	101.64	.20977	1.582	101.58	.20871
170	1.963	103.33	.21466	1.829	103.28	.21344	1.713	103.23	.21232	1.610	103.17	.21125
180	1.997	104.93	.21719	1.860	104.88	.21597	1.743	104.83	.21486	1.638	104.78	.21379
190	2.030	106.55	.21967	1.891	106.49	.21846	1.772	106.45	.21735	1.666	106.40	.21629
200	2.063	108.17	0.22216	1.923	108.12	0.22096	1.802	108.08	0.21985	1.693	108.03	0.21878
210	2.096	109.81	.22462	1.954	109.76	.22342	1.831	109.72	.22231	1.721	109.67	.22125
220	2.129	111.46	.22705	1.986	111.41	.22588	1.860	111.36	.22476	1.749	111.32	.22370
230	2.163	113.12	.22949	2.017	113.08	.22830	1.889	113.03	.22718	1.776	112.98	.22613
240	2.196	114.80	.23191	2.048	114.75	.23072	1.918	114.72	.22960	1.804	114.66	.22856
250	2.229	116.49	0.23430	2.079	116.44	0.23312	1.948	116.41	0.23200	1.833	116.35	0.23097
260	2.262	118.19	.23669	2.110	118.15	.23550	1.977	118.11	.23439	1.860	118.06	.24335
270	2.295	119.91	.23905	2.141	119.87	.23787	2.006	119.82	.23676	1.888	119.79	.23573
280	2.329	121.65	.24141	2.172	121.60	.24023	2.035	121.55	.23912	1.916	121.54	.23809
290	......	......	......	......	......	......	2.065	123.30	.24146	1.944	123.31	.24043

Temp. °F.	Abs. Pressure 36 lb./in.^{2} Gage Pressure 21.3 lb./in.^{2} (Sat'n. Temp. 20.4° F.)			Abs. Pressure 38 lb./in.^{2} Gage Pressure 23.3 lb./in.^{2} (Sat'n. Temp. 23.2° F.)			Abs. Pressure 40 lb./in.^{2} Gage Pressure 25.3 lb./in.^{2} (Sat'n. Temp. 25.9° F.)			Abs. Pressure 42 lb./in.^{2} Gage Pressure 27.3 lb./in.^{2} (Sat'n. Temp. 28.5° F.)		
(at sat'n)	*(1.113)*	*(80.54)*	*(0.16947)*	*(1.058)*	*(80.86)*	*(0.16931)*	*(1.009)*	*(81.16)*	*(0.16914)*	*(0.963)*	*(81.44)*	*(0.16897)*
30	1.140	81.90	0.17227	1.076	81.82	0.17126	1.019	81.76	0.17030	0.967	81.65	0.16939
40	1.168	83.35	.17518	1.103	83.27	.17418	1.044	83.20	.17322	0.991	83.10	.17231
50	1.196	84.81	0.17806	1.129	84.72	0.17706	1.070	84.65	0.17612	1.016	84.56	0.17521
60	1.223	86.27	.18089	1.156	86.19	.17991	1.095	86.11	.17896	1.040	86.03	.17806
70	1.250	87.74	.18369	1.182	87.67	.18272	1.120	87.60	.18178	1.063	87.51	.18086
80	1.278	89.22	.18647	1.208	89.16	.18551	1.144	89.09	.18455	1.087	89.00	.18365
90	1.305	90.71	.18921	1.234	90.66	.18826	1.169	90.58	.18731	1.110	90.50	.18640
100	1.332	92.22	0.19193	1.260	92.17	0.19096	1.194	92.09	0.19004	1.134	92.01	0.18913
110	1.359	93.75	.19462	1.285	93.69	.19365	1.218	93.62	.19272	1.158	93.54	.19184
120	1.386	95.28	.19729	1.310	95.22	.19631	1.242	95.15	.19538	1.181	95.09	.19451
130	1.412	96.82	.19991	1.336	96.76	.19895	1.267	96.70	.19803	1.204	96.64	.19714
140	1.439	98.37	.20254	1.361	98.32	.20157	1.291	98.26	.20066	1.227	98.20	.19979
150	1.465	99.93	0.20512	1.387	99.89	0.20416	1.315	99.83	0.20325	1.250	99.77	0.20237
160	1.492	101.51	.20770	1.412	101.47	.20673	1.340	101.42	.20583	1.274	101.36	.20496
170	1.518	103.11	.21024	1.437	103.07	.20929	1.364	103.02	.20838	1.297	102.96	.20751
180	1.545	104.72	.21278	1.462	104.67	.21183	1.388	104.63	.21092	1.320	104.57	.21005
190	1.571	106.34	.21528	1.487	106.29	.21433	1.412	106.25	.21343	1.343	106.19	.21256
200	1.597	107.97	0.21778	1.512	107.93	0.21681	1.435	107.88	0.21592	1.365	107.82	0.21505
210	1.623	109.61	.22024	1.537	109.57	.21928	1.459	109.52	.21840	1.388	109.47	.21754
220	1.650	111.27	.22270	1.562	111.22	.22176	1.482	111.17	.22085	1.411	111.12	.22000
230	1.676	112.94	.22513	1.587	112.89	.22419	1.506	112.84	.22329	1.434	112.80	.22244
240	1.702	114.62	.22756	1.612	114.58	.22662	1.530	114.52	.22572	1.457	114.49	.22486
250	1.728	116.31	0.22996	1.637	116.28	0.22903	1.554	116.21	0.22813	1.480	116.19	0.22728
260	1.754	118.02	.23235	1.662	117.99	.23142	1.577	117.92	.23052	1.502	117.90	.22967
270	1.780	119.74	.23472	1.687	119.71	.23379	1.601	119.65	.23289	1.524	119.62	.23204
280	1.807	121.47	.23708	1.712	121.45	.23616	1.625	121.40	.23526	1.547	121.36	.23441
290	1.833	123.22	.23942	1.737	123.20	.23850	1.649	123.15	.23760	1.570	123.11	.23675
300	......	....	....	1.762	124.95	0.24083	1.673	124.92	0.23994	1.592	124.87	0.23909

TABLE 2A-13. PROPERTIES OF SUPERHEATED VAPOR, FREON 12 (*Continued*)

Temp. °F.	Abs. Pressure 44 lb./in.² Gage Pressure 29.3 lb./in.² (Sat'n. Temp. 31.0° F.)			Abs. Pressure 46 lb./in.² Gage Pressure 31.3 lb./in.² (Sat'n. Temp. 33.5° F.)			Abs. Pressure 48 lb./in.² Gage Pressure 33.13 lb./in² (Sat'n. Temp. 35.8° F.)			Abs. Pressure 50 lb./in.² Gage Pressure 35.3 lb /in.² (Sat'n. Temp. 38.3° F.)		
t	*V*	*H*	*S*	*V*	*H*	*S*	*V*	*H*	*S*	*V*	*H*	*S*
(at sat'n)	*(0.922)*	*(81.72)*	*(0.16882)*	*(0.885)*	*(82.00)*	*(0.16867)*	*(0.849)*	*(82.25)*	*(0.16855)*	*(0.817)*	*(82.52)*	*(0.16841)*
40	0.943	83.03	0.17142	0.899	82.94	0.17057	0.858	82.85	0.16974	0.821	82.76	0.16895
50	0.966	84.48	0.17432	0.921	84.40	0.17347	0.880	84.32	0.17266	0.842	84.24	0.17187
60	0.989	85.96	.17717	0.943	85.88	.17633	0.902	85.80	.17554	0.863	85.72	.17475
70	1.012	87.45	.18000	0.965	87.37	.17916	0.923	87.29	.17837	0.884	87.22	.17760
80	1.035	88.94	.18279	0.988	88.88	.18198	0.944	88.79	.18117	0.904	88.72	.18040
90	1.058	90.44	.18556	1.010	90.39	.18474	0.965	90.30	.18394	0.924	90.23	.18317
100	1.080	91.95	0.18828	1.031	91.90	0.18746	0.986	91.82	0.18668	0.944	91.75	0.18591
110	1.103	93.48	.19099	1.053	93.43	.19016	1.007	93.35	.18939	0.964	93.29	.18862
120	1.125	95.02	.19367	1.074	94.96	.19285	1.028	94.89	.19208	0.984	94.83	.19132
130	1.147	96.57	.19630	1.096	96.51	.19551	1.048	96.44	.19472	1.004	96.39	.19397
140	1.170	98.14	.19895	1.117	98.08	.19814	1.069	98.01	.19737	1.024	97.96	.19662
150	1.192	99.72	0.20154	1.139	99.66	0.20075	1.089	99.59	0.19997	1.044	99.54	0.19923
160	1.214	101.31	.20412	1.160	101.25	.20333	1.110	101.18	.20256	1.064	101.14	.20182
170	1.236	102.91	.20667	1.181	102.85	.20588	1.130	102.79	.20513	1.084	102.75	.20439
180	1.258	104.52	.20922	1.202	104.46	.20843	1.150	104.40	.20766	1.103	104.36	.20694
190	1.280	106.14	.21173	1.223	106.09	.21094	1.170	106.02	.21017	1.123	105.98	.20946
200	1.302	107.78	0.21424	1.244	107.73	0.21344	1.191	107.66	0.21269	1.142	107.62	0.21196
210	1.324	109.42	.21672	1.265	109.38	.21592	1.211	109.31	.21517	1.162	109.28	.21444
220	1.346	111.08	.21918	1.286	111.04	.21839	1.231	110.98	.21763	1.181	110.95	.21691
230	1.367	112.75	.22161	1.307	112.71	.22083	1.251	112.66	.22007	1.200	112.62	.21935
240	1.389	114.44	.22405	1.327	114.39	.22326	1.271	114.35	.22251	1.220	114.31	.22179
250	1.411	116.14	0.22646	1.348	116.09	0.22567	1.291	116.05	0.22492	1.239	116.00	0.22419
260	1.432	117.85	.22885	1.369	117.81	.22806	1.311	117.77	.22731	1.258	117.71	.22660
270	1.454	119.57	.23123	1.390	119.54	.23044	1.331	119.49	.22970	1.277	119.44	.22898
280	1.475	121.31	.23359	1.410	121.27	.23281	1.351	121.23	.23207	1.296	121.18	.23134
290	1.496	123.06	.23592	1.431	123.02	.23515	1.370	122.98	.23440	1.314	122.93	.23367
300	1.518	124.82	.23826	1.452	124.79	0.23749	1.390	124.75	0.23674	1.332	124.69	0.23600
310	1.539	126.59	.24058	1.472	126.57	.23981	1.410	126.53	.23907	1.350	126.45	.23831

Temp. °F.	Abs. Pressure 52 lb./in.^{2} Gage Pressure 37.3 lb./in.^{2} (Sat'n. Temp. 40.4° F.)			Abs. Pressure 54 lb./in.^{2} Gage Pressure 39.3 lb./in.^{2} (Sat'n. Temp. 42.5° F.)			Abs. Pressure 56 lb./in.^{2} Gage Pressure 41.3 lb./in.^{2} (Sat'n. Temp. 44.6° F.)			Abs. Pressure 58 lb./in.^{2} Gage Pressure 43.3 lb./in.^{2} (Sat'n. Temp. 46.7° F.)		
(at sat'n)	*(0.788)*	*(82.75)*	*(0.16831)*	*(0.759)*	*(82.98)*	*(0.16820)*	*(0.734)*	*(83.22)*	*(0.16810)*	*(0.710)*	*(83.44)*	*(0.16800)*
50	0.808	84.17	0.17114	0.774	84.07	0.17036	0.744	83.99	0.16965	0.716	83.91	0.16896
60	0.827	85.65	.17400	0.794	85.56	.17326	0.763	85.48	.17255	0.734	85.40	.17185
70	0.847	87.14	.17684	0.814	87.06	.17612	0.782	86.98	.17541	0.752	86.90	.17471
80	0.867	88.64	.17966	0.833	88.57	.17894	0.801	88.49	.17824	0.770	88.41	.17753
90	0.886	90.15	.18244	0.852	90.08	.18172	0.819	90.01	.18102	0.788	89.93	.18033
100	0.906	91.68	0.18518	0.871	91.61	0.18446	0.837	91.54	0.18377	0.806	91.46	0.18309
110	0.925	93.22	.18789	0.890	93.16	.18718	0.856	93.08	.18651	0.824	93.00	.18583
120	0.945	94.77	.19059	0.908	94.71	.18989	0.874	94.63	.18921	0.842	94.55	.18854
130	0.964	96.33	.19325	0.927	96.27	.19255	0.892	96.19	.19188	0.860	96.11	.19122
140	0.983	97.90	.19590	0.945	97.84	.19520	0.910	97.77	.19453	0.877	97.68	.19387
150	1.002	99.48	0.19850	0.964	99.43	0.19782	0.928	99.36	0.19715	0.894	99.26	0.19648
160	1.021	101.07	.20109	0.982	101.03	.20043	0.946	100.96	.19975	0.912	100.86	.19908
170	1.040	102.68	.20365	1.001	102.64	.20299	0.964	102.57	.20232	0.929	102.47	.20166
180	1.059	104.30	.20621	1.019	104.25	.20554	0.981	104.19	.20487	0.946	104.09	.20423
190	1.078	105.93	.20873	1.037	105.88	.20806	0.999	105.83	.20739	0.963	105.72	.20676
200	1.097	107.58	0.21125	1.055	107.52	0.21057	1.016	107.48	0.20991	0.980	107.36	0.20927
210	1.116	109.23	.21374	1.073	109.17	.21305	1.034	109.14	.21241	0.997	109.02	.21177
220	1.134	110.89	.21620	1.091	110.84	.21553	1.051	110.81	.21487	1.014	110.70	.21424
230	1.153	112.56	.21865	1.109	112.51	.21797	1.068	112.49	.21731	1.031	112.39	.21669
240	1.172	114.26	.22110	1.127	114.20	.22042	1.086	114.18	.21977	1.048	114.10	.21914
250	1.190	115.96	0.22352	1.145	115.91	0.22283	1.103	115.88	0.22218	1.064	115.82	0.22155
260	1.208	117.67	.22591	1.163	117.63	.22523	1.120	117.59	.22458	1.081	117.55	.22396
270	1.227	119.40	.22829	1.181	119.37	.22762	1.138	119.31	.22698	1.098	119.29	.22635
280	1.245	121.14	.23065	1.199	121.11	.22999	1.155	121.05	.22934	1.114	121.04	.22871
290	1.263	122.90	.23299	1.216	122.86	.23233	1.172	122.80	.23169	1.130	122.80	.23105
300	1.281	124.66	0.23532	1.234	124.63	0.23467	1.189	124.57	0.23403	1.147	124.57	0.23340
310	1.298	126.42	.23763	1.251	126.40	.23699	1.206	126.36	.23635	1.164	126.35	.23574
320	....	....	....	....	....	....	1.223	128.17	.23867	1.180	128.14	.23806

TABLE 2A–13. PROPERTIES OF SUPERHEATED VAPOR, FREON 12 (*Continued*)

Temp. °F.	Abs. Pressure 60 lb./in.² Gage Pressure 45.3 lb./in.² (Sat'n. Temp. 48.7° F.)			Abs. Pressure 70 lb./in.² Gage Pressure 55.3 lb./in.² (Sat'n. Temp. 57.9° F.)			Abs. Pressure 80 lb./in.² Gage Pressure 65.3 lb./in.² (Sat'n. Temp. 66.3° F.)			Abs. Pressure 90 lb./in.² Gage Pressure 75.3 lb./in.² (Sat'n. Temp. 73.9° F.)		
t	*V*	*H*	*S*	*V*	*H*	*S*	*V*	*H*	*S*	*V*	*H*	*S*
(at sat'n)	*(0.688)*	*(83.65)*	*(0.16791)*	*(0.594)*	*(84.61)*	*(0.16749)*	*(0.581)*	*(85.45)*	*(0.16716)*	*(0.465)*	*(86.21)*	*(0.16685)*
50	0.690	83.83	0.16829	......	....	....	......	....	....	......	....	....
60	0.708	85.33	.17120	0.597	84.94	1.6810	......	....	....	......	....	....
70	0.726	86.84	.17407	0.612	86.44	.17097	0.526	86.01	0.16819	......	....	....
80	0.743	88 35	.17689	0.628	87.96	.17382	0.540	87.56	.17108	0.473	87.18	0.16862
90	0.760	89.87	.17968	0.643	89.49	.17665	0.554	89.12	.17394	0.486	88.74	.17149
100	0.778	91.41	0.18246	0.658	91.03	0.17943	0 568	90.68	0 17675	0.499	90.31	0.17433
110	0.795	92.96	.18519	0 673	92.59	.18219	0.582	92.26	.17954	0.511	91.89	.17713
120	0 812	94 51	.18789	0.689	94.16	.18493	0.596	93.84	.18229	0 523	93.48	.17990
130	0.829	96.07	.19056	0.704	95.75	.18763	0.609	95.43	.18500	0.535	95.08	.18262
140	0.846	97.65	.19323	0.719	97.34	.19030	0.623	97.03	.18771	0.547	96.69	.18533
150	0.863	99.24	0.19585	0.733	98.94	0.19293	0.636	98.64	0.19035	0.559	98.31	0.18799
160	0.880	100.84	.19846	0.743	100.54	.19555	0.649	100.26	.19298	0.571	99.94	.19065
170	0.897	102.45	.20104	0.763	102.16	.19814	0.662	101.88	.19558	0.584	101.58	.19327
180	0.913	104.07	.20360	0.777	103.80	.20071	0.675	103.52	.19817	0.596	103.23	.19588
190	0.930	105 71	.20613	0.792	105.45	.20325	0.688	105.18	.20073	0.607	104.89	.19845
200	0.946	107.36	0.20865	0.806	107.10	0.20579	0.701	106.84	0.20328	0.619	106 56	0.20101
210	0.962	109.02	.21113	0.820	108.76	.20829	0.714	108.51	.20580	0.630	108.24	.20353
220	0.979	110 69	.21361	0.835	110.43	.21079	0 726	110.19	.20828	0.642	109.93	.20603
230	0.995	112.37	.21607	0.849	112.13	.21325	0.739	111.88	.21076	0.653	111.63	.20852
240	1.012	114.06	.21853	0.863	113.83	.21570	0.751	113.58	.21321	0.665	113.35	.21100
250	1.028	115.77	0 22094	0.878	115.55	0.21815	0.764	115.30	0 21566	0.676	115.08	0.21345
260	1.044	117.49	.22334	0.892	117.28	.22057	0.777	117.03	.21809	0.688	116.82	.21589
270	1.060	119.23	.22573	0.906	119.02	.22296	0.789	118.78	.22049	0.699	118.57	.21831
280	1.076	120.97	.22810	0.920	120.76	.22534	0.802	120.54	.22289	0.710	120.33	.22070
290	1.092	122.73	.23045	0.934	122.52	.22770	0.814	122.30	.22525	0.721	122.10	.22306
300	1.108	124.50	0.23280	0.948	124.29	0.23006	0.826	124 08	0.22760	0.732	123.88	0.22542
310	1.124	126.28	.23513	0.961	126.07	.23239	0.839	125.88	.22995	0.743	125.67	.22776
320	1.140	128.07	.23745	0.975	127.88	.23471	0.851	127.70	.23229	0.754	127.48	.23008
330	...	....	....	0.989	129 70	.23702	0.864	129.52	.23461	0.765	129.51	.23240

Temp. °F.	Abs. Pressure 100 lb./in.² Gage Pressure 85.3 lb./in.² (Sat'n. Temp. 80.9° F)			Abs. Pressure 110 lb /in.² Gage Pressure 95.3 lb /in.² (Sat'n. Temp. 87.3°F.)			Abs. Pressure 120 lb /in.² Gage Pressure 105.3 lb./in.² (Sat'n. Temp. 93.4° F.)			Abs. Pressure 130 lb./in.² Gage Pressure 115.3 lb./in.² (Sat'n. Temp. 99.1° F.)		
(at sat'n)	*(0.419)*	*(86.89)*	*(0.16659)*	*(0.382)*	*(87.50)*	*(0.16635)*	*(0.350)*	*(88.05)*	*(0.16610)*	*(0.323)*	*(88.547)*	*(0.16588)*
90	0.430	88.32	0.16926	0.385	87.91	0.16711	......	....	....	......	......	....
100	0.442	89.93	0.17210	0 396	89.51	0.17001	0.357	89 13	0.16803	0.324	88 69	0.16615
110	0.454	91.54	.17493	0.407	91.12	.17287	0.367	90.75	.17090	0.333	90.33	.16905
120	0.465	93.15	.17773	0 417	92.74	.17568	0.377	92 38	.17374	0.343	91.98	.17193
130	0.477	94.76	.18049	0.428	94.37	.17845	0.387	94.01	.17654	0.353	93.64	.17476
140	0.488	96.37	.18321	0.438	96.01	.18122	0.397	95.65	.17932	0.362	95.30	.17756
150	0.499	97.99	0.18590	0.449	97.66	0.18394	0 407	97.30	0.18207	0.371	96.97	0.18030
160	0.510	99.63	.18856	0.459	99.31	.18660	0.417	98.96	.18474	0 380	98.65	.18302
170	0 521	101.28	.19120	0.469	100.97	.18924	0.426	100.63	.18743	0.389	100 34	.18571
180	0.531	102.94	.19381	0.479	102.64	.19187	0 436	102 31	.19011	0.398	102 04	.18839
190	0.542	104.61	.19638	0.489	104.32	.19447	0.445	104.00	.19271	0.407	103.74	.19102
200	0.553	106.29	0.19894	0.499	106.01	0.19706	0 454	105.70	0.19529	0.416	105.45	0.19362
210	0.563	107.98	.20148	0.509	107.71	.19962	0.463	107.41	.19785	0.424	107.16	.19620
220	0.574	109.68	.20401	0.519	109.42	.20216	0.472	109.13	.20041	0 433	108 89	.19877
230	0.585	111.39	.20650	0.528	111 14	.20464	0.482	110 86	.20294	0.442	110.62	.20130
240	0.595	113.11	.20899	0.538	112.87	.20712	0.491	112.60	.20545	0.450	112.36	.20382
250	0.606	114.84	0.21145	0 548	114.61	0.20959	0 500	114 35	0 20792	0 458	114.11	0 20629
260	0.616	116 58	.21389	0 557	116.36	.21205	0 508	116 11	.21035	0 467	115 87	.20876
270	0.626	118 33	.21631	0 567	118.12	.21448	0 517	117 88	.21279	0.475	117.64	.21122
280	0.636	120.10	.21870	0 576	119.89	.21690	0 526	119.66	.21521	0 483	119.42	.21364
290	0.646	121.88	.22108	0.586	121.68	.21930	0.534	121.45	.21760	0.492	121.21	.21605
300	0.657	123.67	0.22347	0.595	123.48	0.22167	0.543	123 25	0.22000	0.500	123.01	0.21846
310	0.667	125.47	.22583	0.605	125.29	.22405	0 552	125 07	.22238	0.508	124.82	.22084
320	0.677	127.28	.22817	0.614	127.11	.22639	0 560	126.90	.22472	0.516	126.64	.22320
330	0.687	129.10	.23050	0.623	128 94	.22872	0.569	128.74	.22707	0.524	128.47	.22554
340	0.697	130.94	.23281	0.632	130.78	.23103	0.578	130.59	.22940	0.531	130.31	.22786
350	0.707	132.80	0.23510	0.641	132.63	0.23333	0.586	132.45	0.23171	0.539	132.17	0.23016
360	0.718	134.68	.23738	0.651	134.50	.23562	0.595	134.32	.23400	0.547	134.05	.23246
370	......	....	....							0 555	135.94	.23475

TABLE 2A-13. PROPERTIES OF SUPERHEATED VAPOR, FREON 12 (*Continued*)

Temp. °F.	Abs. Press. 140 lb./in.² Gage Press. 125.3 lb./in.² (Sat'n. Temp. 104.5°F.)			Abs. Press. 160 lb./in.² Gage Press. 145.3 lb./in.² (Sat'n. Temp. 114.5°F.)			Abs. Press. 180 lb./in.² Gage Press. 165.3 lb./in.² (Sat'n. Temp. 123.7°F.)			Abs. Press. 200 lb./in.² Gage Press. 185.3 lb./in.² (Sat'n. Temp. 132.1°F.)			Abs. Press. 220 lb./in.² Gage Press. 205.3 lb./in.² (Sat'n. Temp. 139.9°F.)		
t	*V*	*H*	*S*	*V*	*H*	*S*	*V*	*H*	*S*	*V*	*H*	*S*	*V*	*H*	*S*
(at sat'n)	*(0.298)*	*(88.99)*	*(0.16566)*	*(0.259)*	*(89.77)*	*(0.16528)*	*(0.228)*	*(90.38)*	*(0.16476)*	*(0.208)*	*(90.86)*	*(0.16424)*	*(0.181)*	*(91.50)*	*(0.16375)*
100	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
110	0.304	89.92	0.16725	......	......	......	......	......	......	......	......	......	......	......	......
120	0.314	91.60	.17021	0.264	90.68	0.16682	......	......	......	......	......	......	......	......	......
130	0.323	93.28	.17306	0.273	92.40	.16977	0.233	91.47	0.16665	......	......	......	......	......	......
140	0.332	94.96	.17590	0.282	94.12	.17269	0.241	93.23	.16964	0.208	92.30	0.16661	0.181	91.52	0.16378
150	0.341	96.65	0.17868	0.290	95.84	0.17553	0.249	94.99	0.17254	0.216	94.10	0.16966	0.188	93.32	0.16685
160	0.350	98.34	.18142	0.298	97.57	.17832	0.257	96.75	.17541	0.224	95.90	.17262	0.195	95.13	.16986
170	0.358	100.03	.18412	0.306	99.31	.18106	0.265	98.52	.17823	0.231	97.70	.17551	0.202	96.94	.17282
180	0.366	101.72	.18678	0.313	101.05	.18377	0.272	100.29	.18102	0.238	99.51	.17838	0.209	98.75	.17576
190	0.374	103.42	.18941	0.321	102.80	.18646	0.280	102.07	.18377	0.245	101.32	.18115	0.216	100.57	.17861
200	0.383	105.14	0.19205	0.329	104.55	0.18913	0.287	103.85	0.18648	0.252	103.13	0.18388	0.223	102.39	0.18142
210	0.391	106.86	.19466	0.336	106.31	.19175	0.294	105.63	.18912	0.258	104.94	.18659	0.229	104.22	.18420
220	0.399	108.59	.19724	0.344	108.07	.19435	0.301	107.42	.19174	0.265	106.76	.18927	0.236	106.05	.18694
230	0.407	110.33	.19976	0.351	109.83	.19693	0.307	109.21	.19433	0.272	108.58	.19192	0.242	107.89	.18962
240	0.415	112.09	.20229	0.358	111.60	.19949	0.314	111.01	.19693	0.278	110.40	.19455	0.248	109.74	.19226
250	0.423	113.85	0.20479	0.366	113.38	0.20203	0.321	112.81	0.19947	0.284	112.23	0.19713	0.254	111.59	0.19487
260	0.431	115.63	.20728	0.373	115.17	.20453	0.327	114.62	.20199	0.290	114.06	.19967	0.259	113.44	.19745
270	0.439	117.42	.20974	0.380	116.97	.20700	0.334	116.44	.20449	0.296	115.89	.20217	0.265	115.30	.20001
280	0.447	119.22	.21219	0.387	118.78	.20946	0.340	118.26	.20698	0.302	117.73	.20467	0.271	117.16	.20255
290	0.455	121.03	.21461	0.394	120.60	.21189	0.347	120.09	.20944	0.308	119.58	.20715	0.277	119.03	.20504
300	0.462	122.85	0.21701	0.401	122.43	0.21432	0.353	121.92	0.21187	0.314	121.44	0.20961	0.282	120.91	0.20753
310	0.470	124.67	.21939	0.408	124.27	.21672	0.359	123.76	.21428	0.320	123.31	.21204	0.288	122.80	.21002
320	0.477	126.50	.22174	0.414	126.12	.21909	0.365	125.61	.21665	0.326	125.19	.21445	0.293	124.70	.21244
330	0.485	128.33	.22411	0.421	127.98	.22145	0.371	127.47	.21904	0.331	127.08	.21685	0.299	126.60	.21485
340	0.492	130.17	.22646	0.428	129.85	.22381	0.377	129.34	.22140	0.337	128.98	.21923	0.304	128.51	.21724
350	0.500	132.02	0.22880	0.435	131.73	0.22616	0.383	131.23	0.22374	0.343	130.89	0.22159	0.309	130.42	0.21960
360	0.507	133.89	.23109	0.442	133.63	.22849	0.390	133.13	.22608	0.348	132.81	.22392	0.314	132.34	.22195
370	0.515	135.78	.23336	0.448	135.55	.23079	0.396	135.05	.22840	0.354	134.74	.22624	0.320	134.27	.22430
380	......	......	......	......	......	......	0.402	136.98	.23072	0.360	136.68	.22856	0.325	136.21	.22665
390	......	......	......	......	......	......	0.408	138.91	.23301	0.365	138.63	.23085	0.330	138.16	.22895
400	......	......	......	......	......	......	0.414	140.85	0.23529	0.370	140.59	0.23314	0.335	140.12	0.23124

DICHLOROMONOFLUOROMETHANE, FREON 21

TABLE 2A-14. PROPERTIES OF SATURATED VAPOR, FREON 21

Temp. °F. *t*	Pressure		Volume		Density		Enthalpy from −40°F.			Entropy from −40°F.		Temp. °F. *t*
	Absolute lbs./in.^{2} *p*	Gage lbs./in.^{2} *g.p.*	Liquid ft.^{3}/lb. V_f	Vapor ft.^{3}/lb. *V*	Liquid lbs./ft.^{3} $1/V_f$	Vapor lbs./ft.^{3} $1/V$	Liquid Btu./lb. *h*	Latent Btu./lb. *L*	Vapor Btu./lb. *H*	Liquid Btu./lb. °F. *s*	Vapor Btu./lb. °F. *S*	
−40	1.358	27.16*	0.01058	32.09	94.52	0.03116	0.00	114.56	114.56	0.0000	0.2730	−40
−38	1.453	26.96*	.01060	30.13	94.38	.03319	0.47	114.33	114.80	.0011	.2723	−38
−36	1.553	26.76*	.01061	28.32	94.23	.03531	0.94	114.10	115.04	.0022	.2716	−36
−34	1.659	26.54*	.01063	26.63	94.08	.03755	1.42	113.86	115.28	.0033	.2709	−34
−32	1.770	26.32*	.01065	25.07	93.93	.03989	1.89	113.63	115.52	.0044	.2702	−32
−30	1.888	26.08*	0.01066	23.61	93.79	0.04236	2.36	113.40	115.76	0.0055	0.2695	−30
−28	2.012	25.82*	.01068	22.25	93.64	.04495	2.83	113.17	116.00	.0066	.2688	−28
−26	2.143	25.56*	.01070	20.98	93.49	.04767	3.30	112.94	116.24	.0077	.2682	−26
−24	2.281	25.28*	.01071	19.80	93.34	.05052	3.77	112.71	116.48	.0088	.2675	−24
−22	2.426	24.98*	.01073	18.69	93.19	.05350	4.24	112.48	116.72	.0099	.2669	−22
−20	2.578	24.67*	0.01075	17.66	93.04	0.05661	4.71	112.25	116.96	0.0109	0.2663	−20
−18	2.739	24.34*	.01077	16.70	92.89	.05990	5.19	112.02	117.21	.0120	.2657	−18
−16	2.907	24.00*	.01078	15.80	92.74	.06330	5.66	111.79	117.45	.0131	.2651	−16
−14	3.083	23.64*	.01080	14.96	92.59	.06686	6.13	111.56	117.69	.0141	.2645	−14
−12	3.269	23.26*	.01082	14.17	92.44	.07060	6.60	111.33	117.93	.0152	.2639	−12
−10	3.463	22.87*	0.01084	13.43	92.28	0.07449	7.07	111.10	118.17	0.0162	0.2633	−10
− 8	3.667	22.45*	.01085	12.73	92.13	.07856	7.55	110.86	118.41	.0173	.2627	− 8
− 6	3.881	22.02*	.01087	12.08	91.98	.08281	8.02	110.63	118.65	.0183	.2622	− 6
− 4	4.104	21.56*	.01089	11.47	91.83	.08722	8.49	110.40	118.89	.0194	.2617	− 4
− 2	4.338	21.09*	.01091	10.89	91.67	.09184	8.97	110.16	119.13	.0204	.2611	− 2
0	4.582	20.59*	0.01093	10.35	91.52	0.09662	9.44	109.93	119.37	0.0214	0.2606	0
2	4.838	20.07*	.01095	9.840	91.36	.1016	9.92	109.69	119.61	.0225	.2601	2
4	5.105	19.53*	.01096	9.361	91.21	.1068	10.39	109.46	119.85	.0235	.2596	4
5†	**5.243**	**19.25***	**.01097**	**9.132**	**91.13**	**.1095**	**10.63**	**109.34**	**119.97**	**.0240**	**.2593**	**5†**
6	5.384	18.96*	.01098	8.910	91.05	.1122	10.86	109.23	120.09	.0245	.2591	6
8	5.674	18.37*	.01100	8.486	90.90	.1178	11.33	109.00	120.33	.0255	.2586	8

10	5.978	17.75*	0.01102	8.085	90.74	0.1237	11.81	108.76	120.57	0.0265	0.2581	10
12	6.294	17.11*	.01104	7.707	90.59	.1298	12.29	108.52	120.81	.0275	.2577	12
14	6.625	16.43*	.01106	7.349	90.43	.1361	12.77	108.28	121.05	.0286	.2572	14
16	6.968	15.73*	.01108	7.012	90.27	.1426	13.25	108.05	121.30	.0296	.2567	16
18	7.325	15.01*	.01110	6.694	90.11	.1494	13.73	107.81	121.54	.0306	.2563	18
20	7.699	14.25*	0.01112	6.392	89.96	0.1565	14.21	107.57	121.78	0.0316	0.2559	20
22	8.087	13.46*	.01114	6.107	89.80	.1638	14.68	107.34	122.02	.0326	.2555	22
24	8.488	12.64*	.01116	5.838	89.64	.1713	15.16	107.10	122.26	.0336	.2550	24
26	8.906	11.79*	.01118	5.584	89.48	.1791	15.64	106.86	122.50	.0346	.2546	26
28	9.341	10.90*	.01120	5.342	89.32	.1872	16.12	106.62	122.74	.0356	.2542	28
30	9.793	9.98*	0.01122	5.112	89.16	0.1956	16.61	106.37	122.98	0.0365	0.2538	30
32	10.26	9.03*	.01124	4.894	89.00	.2043	17.09	106.13	123.22	.0375	.2534	32
34	10.75	8.03*	.01126	4.688	88.84	.2133	17.58	105.88	123.46	.0385	.2530	34
36	11.26	7.00*	.01128	4.492	88.68	.2226	18.07	105.64	123.71	.0395	.2526	36
38	11.78	5.94*	.01130	4.306	88.52	.2322	18.55	105.40	123.95	.0405	.2523	38
40	12.32	4.84*	0.01132	4.130	88.35	0.2421	19.04	105.15	124.19	0.0414	0.2519	40
42	12.88	3.70*	.01134	3.963	88.19	.2523	19.53	104.90	124.43	.0424	.2516	42
44	13.46	2.52*	.01136	3.804	88.03	.2629	20.02	104.65	124.67	.0434	.2512	44
46	14.07	1.28*	.01138	3.651	87.86	.2739	20.51	104.40	124.91	.0444	.2509	46
48	14.69	0.01*	.01140	3.507	87.70	.2852	21.00	104.15	125.15	.0453	.2505	48
50	15.33	0.63	0.01142	3.370	87.54	0.2968	21.49	103.90	125.39	0.0463	0.2502	50
52	16.00	1.30	.01145	3.239	87.37	.3088	21.99	103.64	125.63	.0473	.2499	52
54	16.69	1.99	.01147	3.114	87.21	.3212	22.48	103.39	125.87	.0482	.2495	54
56	17.40	2.70	.01149	2.995	87.04	.3339	22.98	103.13	126.11	.0492	.2492	56
58	18.14	3.44	.01151	2.881	86.88	.3471	23.48	102.88	126.36	.0502	.2489	58
60	18.90	4.20	0.01153	2.773	86.71	0.3606	23.98	102.62	126.60	0.0511	0.2486	60
62	19.69	4.99	.01155	2.669	86.54	.3747	24.49	102.35	126.84	.0521	.2483	62
64	20.50	5.80	.01158	2.570	86.38	.3891	24.99	102.09	127.08	.0530	.2480	64
66	21.34	6.64	.01160	2.476	86.21	.4039	25.49	101.83	127.32	.0540	.2477	66
68	22.20	7.50	.01162	2.386	86.04	.4191	25.99	101.57	127.56	.0549	.2474	68

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* Inches of mercury below one atmosphere.

† Standard ton temperature.

TABLE 2A-14. PROPERTIES OF SATURATED VAPOR, FREON 21 (*Continued*)

Temp °F. t	Pressure		Volume		Density		Enthalpy from −40°F.			Entropy from −40°F.		Temp. °F. t
	Absolute lbs./in.^{2} p	Gage lbs./in.^{2} $g.p.$	Liquid ft.^{3}/lb. V_f	Vapor ft.^{3}/lb. V	Liquid lbs./ft.^{3} $1/V_f$	Vapor lbs./ft.^{3} $1/V$	Liquid Btu./lb. h	Latent Btu./lb. L	Vapor Btu./lb. H	Liquid Btu./lb.°F. s	Vapor Btu./lb.°F. S	
70	23.08	8.38	0.01164	2.300	85.87	0.4346	26.49	101.30	127.79	0.0559	0 2471	70
72	24.00	9.30	.01167	2 218	85.71	.4508	27.00	101.03	128.03	.0568	.2469	72
74	24.95	10.25	.01169	2.139	85.54	.4675	27.51	100.76	128.27	.0577	.2466	74
76	25.92	11.22	.01171	2.064	85.37	.4846	28.02	100.49	128.51	.0587	.2463	76
78	26.93	12.23	.01174	1.992	85.20	.5021	28.52	100.22	128.74	.0596	.2460	78
80	27.96	13.26	0.01176	1.923	85.03	0.5201	29.03	99.95	128.98	0.0606	0.2458	80
82	29.02	14.32	.01178	1.857	84.86	.5386	29.54	99.67	129.21	.0615	.2455	82
84	30.11	15.41	.01181	1.794	84.69	.5575	30.05	99.39	129.44	.0624	.2453	84
86†	31.23	16.53	.01183	1.733	84.52	.5770	30.56	99.12	129.68	.0634	.2450	86†
88	32.39	17.69	.01186	1.675	84.34	.5971	31.07	98.84	129.91	.0643	.2448	88
90	33.58	18.88	0.01188	1.619	84.17	0.6177	31.59	98.55	130.14	0.0652	0.2446	90
92	34.80	20.10	.01190	1.565	84.00	.6388	32.11	98.27	130.38	.0662	.2443	92
94	36.06	21.36	.01193	1.513	83.83	.6606	32.63	97.98	130.61	.0671	.2441	94
96	37.35	22.65	.01195	1.464	83.65	.6829	33.15	97.69	130.84	.0680	.2439	96
98	38.68	23.98	.01198	1.417	83.48	.7058	33.67	97.40	131.07	.0690	.2437	98
100	40.04	25.34	0.01200	1.371	83.31	0.7292	34.18	97.11	131.29	0.0699	0.2434	100
102	41.44	26.74	.01203	1.327	83.13	.7533	34.70	96.82	131.52	.0708	.2432	102
104	42.88	28.18	.01205	1.285	82.96	.7779	35.23	96.52	131.75	.0717	.2430	104
106	44.35	29.65	.01208	1.245	82.78	.8033	35.75	96.22	131.97	.0727	.2428	106
108	45.85	31.15	.01211	1.206	82.61	.8291	36.27	95.93	132.20	.0736	.2426	108
110	47.40	32.70	0.01213	1.169	82.43	0.8557	36.79	95.63	132.42	0.0745	0.2424	110
112	48.98	34.28	.01216	1.133	82.25	.8827	37.32	95.32	132.64	.0754	.2422	112
114	50.61	35.91	.01218	1.098	82.08	.9107	37.86	95.01	132.87	.0763	.2420	114
116	52.28	37.58	.01221	1.064	81.90	.9393	38.39	94.70	133.09	.0773	.2418	116
118	54.00	39.30	.01224	1.032	81.72	.9688	38.92	94.39	133.31	.0782	.2416	118

120	55.75	41.05	0.01226	1.001	81.54	0.9986	39.46	94.08	133.53	0.0791	0.2414	120
122	57.54	42.84	.01229	0.9714	81.36	1.029	39.99	93.76	133.75	.0800	.2412	122
124	59.38	44.68	.01232	.9426	81.19	1.061	40.53	93.44	133.97	.0809	.2410	124
126	61.26	46.56	.01235	.9147	81.01	1.093	41.06	93.12	134.18	.0818	.2409	126
128	63.18	48.48	.01237	.8881	80.83	1.126	41.60	92.80	134.40	.0827	.2407	128
130	65.15	50.45	0.01240	0.8623	80.65	1.160	42.13	92.48	134.61	0.0837	0.2405	130
132	67.17	52.47	.01243	.8372	80.47	1.195	42.67	92.15	134.82	.0846	.2403	132
134	69.23	54.53	.01246	.8133	80.28	1.230	43.22	91.82	135.03	.0855	.2402	134
136	71.34	56.64	.01248	.7900	80.10	1.266	43.76	91.48	135.24	.0864	.2400	136
138	73.51	58.81	.01251	.7675	79.92	1.303	44.31	91.14	135.45	.0873	.2398	138
140	75.72	61.02	0.01254	0.7457	79.74	1.341	44.86	90.80	135.66	0.0882	0.2396	140
142	77.97	63.27	.01257	.7248	79.56	1.380	45.41	90.46	135.87	.0891	.2395	142
144	80.29	65.59	.01260	.7044	79.37	1.420	45.96	90.11	136.07	.0900	.2393	144
146	82.64	67.94	.01263	.6849	79.19	1.461	46.51	89.77	136.28	.0909	.2392	146
148	85.05	70.35	.01266	.6659	79.01	1.502	47.06	89.42	136.48	.0918	.2390	148
150	87.51	72.81	0.01269	0.6476	78.82	1.544	47.62	89.06	136.68	0.0927	0.2388	150
152	90.01	75.31	.01272	.6300	78.64	1.587	48.18	88.71	136.89	.0936	.2387	152
154	92.58	77.88	.01275	.6128	78.45	1.631	48.74	88.35	137.09	.0945	.2385	154
156	95.20	80.50	.01278	.5962	78.27	1.677	49.30	87.99	137.29	.0954	.2384	156
158	97.88	83.18	.01281	.5801	78.08	1.724	49.87	87.62	137.49	.0963	.2382	158
160	100.6	85.91	0.01284	0.5646	77.90	1.771	50.43	87.26	137.69	0.0972	0.2381	160

† Standard ton temperature.

TABLE 2A-15. PROPERTIES OF SUPERHEATED VAPOR, FREON 21

Temp. °F.	Abs. Pressure 1.2 lb./in.² Gauge Pressure 27.48 in. Vac. (Sat'n. Temp. —43.6°F.)			Abs. Pressure 1.4 lb./in.² Gauge Pressure 27.07 in. Vac. (Sat'n. Temp. —39.1°F.)			Abs. Pressure 1.6 lb./in.² Gauge Pressure 26.66 in. Vac. (Sat'n. Temp. —35.1°F.)			Abs. Pressure 1.8 lb./in.² Gauge Pressure 26.26 in. Vac. (Sat'n. Temp. —31.5°F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(at sat'n)	(36.02)	(114.13)	(0.2744)	(31.21)	(114.67)	(0.2727)	(27.56)	(115.15)	(0.2713)	(24.69)	(115.58)	(0.2700)
−40	36.34	114.57	0.2754	.....	.....	.....	.....	.....	.....	.....	.....	.....
−30	37.21	115.80	.2783	31.88	115.79	0.2753	27.88	115.78	0.2727	24.77	115.77	0.2704
−20	38.08	117.03	.2812	32.63	117.02	.2781	28.53	117.01	.2755	25.35	117.00	.2733
−10	38.95	118.28	.2840	33.38	118.27	.2809	29.19	118.26	.2783	25.93	118.25	.2761
0	39.83	119.54	0.2867	34.12	119.53	0.2837	29.85	119.52	0.2811	26.52	119.51	0.2788
10	40.70	120.80	.2894	34.87	120.79	.2864	30.50	120.79	.2839	27.10	120.78	.2816
20	41.57	122.08	.2921	35.62	122.07	.2891	31.15	122.07	.2866	27.68	122.06	.2843
30	42.44	123.38	.2948	36.37	123.36	.2918	31.81	123.36	.2893	28.26	123.35	.2870
40	43.32	124.69	.2975	37.11	124.67	.2945	32.46	124.67	.2919	28.85	124.66	.2896
50	44.19	126.01	0.3001	37.86	126.00	0.2971	33.12	126.00	0.2945	29.43	125.99	0.2923
60	45.06	127.35	.3027	38.61	127.34	.2997	33.77	127.35	.2971	30.01	127.34	.2949
70	45.93	128.71	.3053	39.36	128.70	.3023	34.43	128.71	.2997	30.59	128.70	.2974
80	46.80	130.09	.3079	40.11	130.08	.3049	35.08	130.09	.3023	31.17	130.08	.3000
90	47.67	131.48	.3104	40.85	131.47	.3074	35.74	131.47	.3048	31.75	131.46	.3025
100	48.54	132.88	0.3129	41.60	132.87	0.3099	36.39	132.87	0.3073	32.34	132.86	0.3050
110	49.42	134.29	.3154	42.34	134.28	.3124	37.04	134.28	.3098	32.92	134.27	.3075
120	50.29	135.71	.3179	43.09	135.70	.3149	37.70	135.70	.3123	33.50	135.69	.3100
130	51.16	137.14	.3203	43.84	137.14	.3173	38.35	137.13	.3148	34.08	137.13	.3125
140	52.03	138.59	.3228	44.59	138.58	.3198	39.00	138.58	.3172	34.66	138.58	.3149
150	52.90	140.06	0.3252	45.33	140.04	0.3222	39.66	140.05	0.3196	35.24	140.05	0.3173
160	53.77	141.55	.3276	46.08	141.53	.3246	40.31	141.54	.3221	35.82	141.53	.3198
170	54.64	143.05	.3300	46.83	143.04	.3270	40.96	143.04	.3245	36.40	143.03	.3222
180	55.51	144.56	.3324	47.57	144.55	.3294	41.62	144.55	.3268	36.98	144.54	.3246
190	56.38	146.08	.3348	48.32	146.07	.3318	42.27	146.07	.3292	37.57	146.06	.3269
200	57.25	147.61	0.3371	49.06	147.60	0.3341	42.93	147.60	0.3316	38.15	147.60	0.3293
210	58.12	149.16	.3394	49.81	149.16	.3365	43.58	149.15	.3339	38.73	149.15	.3316
220	58.99	150.73	.3418	50.56	150.73	.3388	44.23	150.72	.3362	39.31	150.72	.3339
230	59.86	152.31	.3441	51.31	152.31	.3411	44.88	152.30	.3385	39.89	152.30	.3362
240	60.73	153.90	.3464	52.05	153.90	.3434	45.54	153.89	.3408	40.47	153.89	.3385
250	61.60	155.51	0.3486	52.80	155.51	0.3457	46.19	155.50	0.3431	41.05	155.50	0.3408

Temp. °F.	Abs. Pressure 2 lb./in.² Gauge Pressure 25.85 in. Vac. (Sat'n. Temp. —28.2°F.)			Abs. Pressure 2.2 lb./in.² Gauge Pressure 25.44 in. Vac. (Sat'n. Temp. —25.2°F.)			Abs. Pressure 2.4 lb /in.² Gauge Pressure 25.04 in. Vac. (Sat'n. Temp. —22.4°F.)			Abs. Pressure 2.6 lb./in.² Gage Pressure 24.63 in. Vac. (Sat'n. Temp. —19.7°F.)		
(at sat'n)	(22.37)	(115.98)	(0.2689)	(20.48)	(116 34)	(0.2679)	(18.88)	(116 67)	(0.2670)	(17.52)	(117.00)	(0.2662)
–20	22.80	116.99	0.2712	20.72	116.98	0.2694	18.98	116.97	0.2677	.....	.....	.....
–10	23.33	118.24	.2740	21.20	118.23	.2722	19.42	118.22	.2705	17.92	118.21	0.2689
0	23.85	119.49	0.2768	21.68	119.49	0.2749	19.86	119.48	0.2732	18.32	119.47	0.2717
10	24.38	120.76	.2795	22.15	120.76	.2777	20.30	120.75	.2760	18.73	120.74	.2744
20	24.90	122.04	.2822	22.63	122.04	.2804	20.73	122.03	.2787	19.13	122.02	.2771
30	25.43	123.34	.2849	23.11	123.33	.2831	21.17	123.32	.2814	19.54	123.31	.2798
40	25.95	124.65	.2876	23.58	124.64	.2857	21.61	124.63	.2840	19.94	124.63	.2825
50	26.47	125.98	0.2902	24.06	125.97	0.2884	22.05	125.96	0.2867	20.34	125.96	0.2851
60	27.00	127.33	.2928	24.54	127.32	.2910	22.48	127.31	.2893	20.75	127.31	.2877
70	27.52	128.69	.2954	25.01	128.68	.2936	22.92	128.67	.2919	21.15	128.67	.2903
80	28.05	130.07	.2979	25.49	130.06	.2961	23.36	130.05	.2944	21.55	130.05	.2929
90	28.57	131.45	.3005	25.97	131.44	.2987	23.80	131.43	.2970	21.96	131.43	.2954
100	29.09	132.85	0.3030	26.44	132.84	0.3012	24.23	132.83	0.2995	22.36	132.83	0.2979
110	29.62	134.26	.3055	26.92	134.25	.3037	24.67	134.24	.3020	22.76	134.24	.3004
120	30.14	135.68	.3080	27.39	135.67	.3061	25.11	135.67	.3045	23.17	135.66	.3029
130	30.66	137.12	.3104	27.87	137.11	.3086	25.54	137.10	.3069	23.57	137.10	.3054
140	31.19	138.57	.3129	28.34	138.56	.3111	25.98	138.55	.3094	23.97	138.55	.3078
150	31.71	140.03	0.3153	28.82	140.03	0.3135	26.41	140.02	0.3118	24.38	140.02	0.3102
160	32.23	141.52	.3177	29.30	141.51	.3159	26.85	141.51	.3142	24.78	141.50	.3126
170	32.76	143.02	.3201	29.77	143.01	.3183	27.29	143.01	.3166	25.18	143.00	.3150
180	33.28	144.53	.3225	30.25	144.52	.3207	27.72	144.52	.3190	25.58	144.51	.3174
190	33.80	146.05	.3249	30.72	146.04	.3230	28.16	146.04	.3213	25.99	146.03	.3198
200	34.33	147.59	0.3272	31.20	147.57	0.3254	28.59	147.58	0.3237	26.39	147.57	0.3221
210	34.85	149.14	.3296	31.68	149.13	.3277	29.03	149.13	.3260	26.79	149.12	.3245
220	35.37	150.71	.3319	32.15	150.70	.3300	29.47	150.70	.3284	27.20	150.69	.3268
230	35.89	152.29	.3342	32.63	152.28	.3324	29.90	152.28	.3307	27.60	152.27	.3291
240	36.42	153.88	.3365	33.10	153.87	.3346	30.34	153.86	.3329	28.00	153.86	.3314
250	36.94	155.49	0.3388	33.58	155.48	0.3369	30.77	155.46	0.3352	28.40	155.47	0.3337
260	.....	.....	.....	34.05	157.09	0.3392	31.21	157.08	0.3375	28.81	157.08	0.3359

TABLE 2A-15. PROPERTIES OF SUPERHEATED VAPOR, FREON 21 (*Continued*)

Temp. °F.	Abs. Pressure 2.8 lb./in.² Gage Pressure 24.22 in. Vac. (Sat'n. Temp. —17.3°F.)			Abs. Pressure 3 lb./in.² Gage Pressure 23.81 in. Vac. (Sat'n. Temp. —14.9°F.)			Abs. Pressure 3.5 lb./in.² Gage Pressure 22.80 in. Vac. (Sat'n. Temp. —9.6°F.)			Abs. Pressure 4 lb./in.² Gage Pressure 21.78 in. Vac. (Sat'n. Temp. —4.9°F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(at sat'n)	(16.36)	(117.29)	(0.2655)	(15.34)	(117.58)	(0.2647)	(13.29)	(118.22)	(0.2632)	(11.74)	(118.78)	(0.2619)
−10	16.63	118.20	0.2675	15.51	118.19	0.2661	.....	.....	.....	.....	.....	.....
0	17.01	119.46	0.2702	15.87	119.45	0.2689	13.58	119.43	0.2659	11.87	119.40	0.2633
10	17.38	120.73	.2730	16.22	120.72	.2716	13.88	120.70	.2686	12.14	120.66	.2660
20	17.76	122.01	.2757	16.57	122.00	.2743	14.19	121.98	.2713	12.40	121.95	.2687
30	18.13	123.31	.2784	16.92	123.30	.2770	14.49	123.27	.2740	12.66	123.25	.2714
40	18.51	124.62	.2810	17.27	124.61	.2797	14.79	124.59	.2767	12.93	124.57	.2741
50	18.88	125.95	0.2837	17.62	125.94	0.2823	15.09	125.92	0.2793	13.19	125.90	0.2767
60	19.26	127.30	.2863	17.97	127.29	.2849	15.39	127.27	.2819	13.45	127.25	.2793
70	19.63	128.66	.2889	18.32	128.65	.2875	15.69	128.63	.2845	13.72	128.61	.2819
80	20.01	130.04	.2914	18.67	130.03	.2901	15.99	130.01	.2871	13.98	129.99	.2845
90	20.38	131.42	.2940	19.02	131.41	.2926	16.29	131.39	.2896	14.24	131.37	.2870
100	20.76	132.82	0.2965	19.37	132.81	0.2951	16.59	132.79	0.2921	14.51	132.77	0.2895
110	21.13	134.23	.2990	19.72	134.22	.2976	16.89	134.20	.2946	14.77	134.18	.2920
120	21.51	135.66	.3015	20.07	135.65	.3001	17.19	135.63	.2971	15.03	135.61	.2945
130	21.88	137.09	.3039	20.42	137.08	.3026	17.49	137.06	.2996	15.29	137.04	.2970
140	22.26	138.54	.3064	20.77	138.53	.3050	17.79	138.51	.3021	15.56	138.49	.2994
150	22.63	140.01	0.3088	21.12	140.00	0.3075	18.09	139.98	0.3045	15.82	139.96	0.3019
160	23.00	141.50	.3112	21.47	141.49	.3099	18.39	141.47	.3069	16.08	141.45	.3043
170	23.38	143.00	.3136	21.82	142.99	.3123	18.69	142.97	.3093	16.35	142.95	.3067
180	23.75	144.51	.3160	22.16	144.50	.3147	18.99	144.48	.3117	16.61	144.46	.3091
190	24.13	146.03	.3184	22.51	146.02	.3170	19.29	146.00	.3140	16.87	145.98	.3114
200	24.50	147.56	0.3207	22.86	147.55	0.3194	19.59	147.54	0.3164	17.13	147.52	0.3138
210	24.88	149.12	.3230	23.21	149.11	.3217	19.89	149.10	.3187	17.39	149.08	.3161
220	25.25	150.69	.3254	23.56	150.68	.3240	20.19	150.67	.3210	17.66	150.65	.3184
230	25.62	152.27	.3277	23.91	152.26	.3263	20.49	152.25	.3233	17.92	152.23	.3207
240	26.00	153.86	.3300	24.26	153.85	.3286	20.79	153.84	.3256	18.18	153.82	.3230
250	26.37	155.46	0.3322	24.61	155.46	0.3309	21.09	155.45	0.3279	18.44	155.43	0.3253
260	26.74	157.07	0.3345	24.96	157.07	0.3332	21.39	157.06	.3302	18.70	157.05	.3276
270	.....	.....	.....	.....	.....	.....	21.68	158.69	0.3325	18.97	158.68	0.3298

Temp. °F.	Abs. Pressure 4.5 lb./in.² Gage Pressure 20.76 in. Vac. (Sat'n. Temp. —0.7°F.)			Abs. Pressure 5 lb./in.² Gage Pressure 19.74 in. Vac. (Sat'n. Temp. +3.2°F.)			Abs. Pressure 5 5 lb./in.² Gage Pressure 18.73 in. Vac. (Sat'n. Temp. 6.8°F.)			Abs. Pressure 6 lb./in.² Gage Pressure 17.71 in. Vac. (Sat'n. Temp. 10.1°F.)		
(at sat'n)	(10.53)	(119.29)	(0.2608)	(9.543)	(119.75)	(0.2598)	(8.737)	(120.19)	(0.2589)	(8.056)	(120.58)	(0.2581)
0	10.54	119.38	0.2610	.....	.....	.....	.....	.....	.....	.....	.....	.....
10	10.78	120.64	.2637	9.687	120.62	0.2616	8.796	120.60	0.2598	.....	.....	.....
20	11.01	121.93	.2664	9.899	121.91	.2644	8.989	121.89	.2625	8.232	121.86	0.2608
30	11.25	123.23	.2691	10.11	123.20	.2671	9.182	123.18	.2652	8.408	123.16	.2635
40	11.48	124.55	.2718	10.32	124.52	.2697	9.375	124.50	.2679	8.585	124.48	.2661
50	11.71	125.88	0.2744	10.53	125.86	0.2724	9.567	125.84	0.2705	8.762	125.81	0.2688
60	11.95	127.23	.2770	10.74	127.21	.2750	9.759	127.19	.2731	8.939	127.17	.2714
70	12.18	128.59	.2796	10.96	128.57	.2776	9.952	128.55	.2757	9.115	128.53	.2740
80	12.42	129.97	.2822	11.17	129.95	.2801	10.14	129.93	.2783	9.291	129.91	.2766
90	12.65	131.35	.2847	11.38	131.33	.2827	10.34	131.31	.2808	9.467	131.29	.2791
100	12.88	132.75	0.2873	11.59	132.73	0.2852	10.53	132.71	0.2834	9.643	132.69	0.2816
110	13.12	134.16	.2898	11.80	134.14	.2877	10.72	134.13	.2858	9.819	134.11	.2841
120	13.35	135.59	.2922	12.01	135.57	.2902	10.91	135.56	.2883	9.995	135.54	.2866
130	13.59	137.03	.2947	12.22	137.01	.2926	11.10	136.99	.2908	10.17	136.97	.2891
140	13.82	138.48	.2971	12.43	138.46	.2951	11.30	138.44	.2932	10.35	138.42	.2915
150	14.06	139.95	0.2996	12.64	139.93	0.2975	11.49	139.91	0.2957	10.52	139.89	0.2940
160	14.29	141.44	.3020	12.85	141.42	.2999	11.68	141.40	.2981	10.70	141.39	.2964
170	14.52	142.94	.3044	13.06	142.92	.3023	11.87	142.91	.3005	10.87	142.89	.2988
180	14.76	144.45	.3068	13.27	144.43	.3047	12.06	144.42	.3029	11.05	144.40	.3012
190	14.99	145.97	.3092	13.48	145.95	.3071	12.25	145.94	.3052	11.22	145.92	.3035
200	15.22	147.51	0.3115	13.69	147.49	0.3094	12.44	147.47	0.3076	11.40	147.45	0.3059
210	15.46	149.06	.3138	13.90	149.04	.3118	12.63	149.03	.3099	11.58	149.01	.3082
220	15.69	150.63	.3162	14.11	150.61	.3141	12.83	150.60	.3123	11.75	150.58	.3106
230	15.92	152.21	.3185	14.32	152.20	.3164	13.02	152.19	.3146	11.93	152.17	.3129
240	16.15	153.81	.3208	14.53	153.80	.3187	13.21	153.79	.3169	12.10	153.76	.3152
250	16.39	155.42	0.3230	14.74	155.41	0.3210	13.40	155.40	0.3191	12.28	155.37	0.3175
260	16.62	157.04	.3253	14.95	157.03	.3233	13.59	157.02	.3214	12.45	156.99	.3197
270	16.85	158.67	.3276	15.16	158.66	.3255	13.78	158.65	.3237	12.63	158.63	.3220
280	17.09	160.30	0.3298	15.37	160.29	0.3278	13.97	160.28	.3259	12.80	160.27	.3242
290	.....	.....	.....	.....	.....	.....	14.16	161.95	0.3282	12.98	161.94	0.3265

TABLE 2A-15. PROPERTIES OF SUPERHEATED VAPOR, FREON 21 (*Continued*)

Temp. °F.	Abs. Pressure 7 lb./in.² Gage Pressure 15.67 in. Vac. (Sat'n. Temp. 16.2°F.)			Abs. Pressure 8 lb./in.² Gage Pressure 13.64 in. Vac. (Sat'n. Temp. 21.6°F.)			Abs. Pressure 9 lb./in.² Gage Pressure 11.60 in. Vac. (Sat'n. Temp. 26.4°F.)			Abs. Pressure 10 lb./in.² Gage Pressure 9.57 in. Vac. (Sat'n. Temp. 30.9°F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(at sat'n)	(6.983)	(121.32)	(0.2567)	(6.169)	(121.96)	(0 2556)	(5.520)	(122.55)	(0.2545)	(5.014)	(123.10)	(0.2536)
20	7.041	121.81	0.2578	.....	.....	.....	.....	.....	.....	.....	.....	.....
30	7.193	123.11	.2605	6.281	123.06	0.2578	5.572	123.02	0.2555	.....	.....	.....
40	7.345	124.43	.2631	6.414	124.39	.2605	5.691	124.34	.2582	5.112	124.30	0.2561
50	7.497	125.76	0.2658	6.547	125.73	0.2631	5.809	125.68	0.2608	5.219	125.63	0.2587
60	7.648	127.12	.2684	6.681	127.08	.2657	5.928	127.04	.2634	5.326	126.99	.2613
70	7.800	128.48	.2710	6.814	128.44	.2683	6.046	128.40	.2660	5.433	128.36	.2639
80	7.951	129.86	.2735	6.947	129.82	.2709	6.165	129.78	.2686	5.540	129.74	.2665
90	8.102	131.25	.2761	7.079	131.21	.2735	6.283	131.17	.2711	5.646	131.13	.2691
100	8.254	132.65	0.2786	7.212	132.61	0.2760	6.402	132.58	0.2737	5.753	132.54	0.2716
110	8.405	134.07	.2311	7.345	134.03	.2785	6.520	133.99	.2762	5.860	133.95	.2741
120	8.556	135.50	.2836	7.477	135.46	.2810	6.638	135.42	.2787	5.966	135.88	.2766
130	8.707	136.93	.2861	7.609	136.90	.2835	6.755	136.86	.2811	6.072	136.82	.2791
140	8.858	138.38	.2885	7.742	138.35	.2859	6.873	138.31	.2836	6.178	138.28	.2815
150	9.009	139.85	0.2910	7.874	139.82	0.2883	6.991	139.78	0.2860	6.285	139.75	0.2840
160	9.160	141.34	.2934	8.006	141.31	.2908	7.109	141.28	.2885	6.391	141.24	.2864
170	9.311	142.85	.2958	8.138	142.82	.2932	7.227	142.79	.2909	6.497	142.75	.2888
180	9.462	144.36	.2982	8.270	144.33	.2956	7.344	144.30	.2933	6.603	144.27	.2912
190	9.612	145.89	.3005	8.402	145.86	.2979	7.462	145.82	.2956	6.709	145.79	.2936
200	9.763	147.43	0.3029	8.534	147.39	0.3003	7.579	147.36	0.2980	6.815	147.33	0.2959
210	9.913	148.98	.3052	8.666	148.95	.3026	7.696	148.92	.3003	6.921	148.89	.2983
220	10.06	150.55	.3076	8.798	150.52	.3050	7.314	150.49	.3027	7.027	150.46	.3006
230	10.21	152.14	.3099	8.930	152.11	.3073	7.932	152.08	.3050	7.133	152.05	.3029
240	10.36	153.74	.3122	9.062	153.70	.3096	8.049	153.68	.3073	7.239	153.65	.3052
250	10.51	155.35	0 3145	9.194	155.31	0.3119	8.166	155.29	0.3096	7.344	155.26	0.3075
260	10.67	156.97	.3167	9.325	156.93	.3141	8.284	156.91	.3118	7.450	156.88	.3098
270	10.82	158.60	.3190	9.457	158.57	.3164	8.401	158.55	.3141	7.555	158.52	.3120
280	10.97	160.25	.3212	9.589	160.22	.3186	8.518	160.20	.3163	7.661	160.17	.3143
290	11.12	161.92	0.3235	9.721	161.89	.3209	8.635	161.87	.3186	7.767	161.84	.3165
800	.....	.....	.....	9.852	163.57	0.3231	8.752	163.54	0.3208	7.872	163.52	0.3187
310	.....	.....	.....	.....	.....	.....	.....	.....	.....	7.978	165.21	0.3210

Temp. °F.	Abs. Pressure 11 lb./in.² Gage Pressure 7.53 in. Vac (Sat'n. Temp. 35.0°F.)			Abs. Pressure 12 lb./in.² Gage Pressure 5.50 in Vac. (Sat'n. Temp. 38.8°F.)			Abs. Pressure 13 lb /in.² Gage Pressure 3.46 in. Vac. (Sat'n Temp. 42.4°F.)			Abs. Pressure 14 lb./in.² Gage Pressure 1.42 in. Vac (Sat'n. Temp. 45.8°F.)		
at sat'n)	(4.589)	(123.59)	(0.2528)	(4.232)	(124.04)	(0.2521)	(3.929)	(124.47)	(0.2515)	(3.667)	(124.88)	(0.2509)
40	4.638	124.25	0.2542	4.243	124.20	0.2524	.....	.....	.....	.....	.....	.....
50	4.735	125.59	0.2568	4.333	125.54	0.2551	3.992	125.49	0.2535	3.700	125.45	0.2520
60	4.833	126.95	.2595	4.422	126.90	.2577	4.075	126.86	.2561	3.777	126.82	.2546
70	4.930	128.32	.2621	4.512	128.28	.2603	4.158	128.23	.2587	3.854	128.19	.2572
80	5.028	129.70	.2646	4.601	129.66	.2629	4.241	129.62	.2613	3.931	129.58	.2598
90	5.125	131.09	.2672	4.691	131.05	.2655	4.323	131.01	.2639	4.008	130.97	.2624
100	5.222	132.50	0.2697	4.780	132.46	0.2680	4.406	132.42	0.2664	4.085	132.38	0.2649
110	5.319	133.92	.2722	4.870	133.88	.2705	4.489	133.84	.2689	4.162	133.80	.2674
120	5.416	135.35	.2747	4.959	135.31	.2730	4.571	135.27	.2714	4.239	135.23	.2699
130	5.513	136.79	.2772	5.047	136.75	.2755	4.653	136.71	.2739	4.315	136.68	.2724
140	5.610	138.24	.2797	5.136	138.20	.2779	4.736	138.17	.2764	4.392	138.13	.2749
150	5.707	139.72	0.2821	5.225	139.68	0.2804	4.818	139.65	0.2788	4.468	139.60	0.2773
160	5.804	141.22	.2845	5.314	141.18	.2828	4.900	141.15	.2812	4.545	141.11	.2798
170	5.900	142.72	.2869	5.403	142.69	.2852	4.982	142.65	.2836	4.621	142.62	.2822
180	5.997	144.23	.2893	5.492	144.20	.2876	5.064	144.17	.2860	4.697	144.13	.2846
190	6.093	145.76	.2917	5.580	145.73	.2900	5.146	145.69	.2884	4.774	145.66	.2869
200	6.190	147.30	0.2940	5.669	147.27	0.2923	5.228	147.23	0.2908	4.850	147.20	0.2893
210	6.286	148.86	.2964	5.757	148.83	.2947	5.310	148.79	.2931	4.926	148.76	.2916
220	6.383	150.43	.2987	5.846	150.41	.2970	5.392	150.37	.2954	5.002	150.33	.2940
230	6.479	152.02	.3010	5.934	151.99	.2993	5.474	151.96	.2978	5.078	151.92	.2963
240	6.576	153.62	.3033	6.023	153.59	.3016	5.555	153.56	.3001	5.154	153.52	.2986
250	6.672	155.23	0.3056	6.111	155.20	0.3039	5.637	155.17	0.3023	5.230	155.14	0.3009
260	6.768	156.85	.3079	6.199	156.82	.3062	5.718	156.79	.3046	5.306	156.77	.3032
270	6.864	158.49	.3102	6.288	158.46	.3085	5.800	158.43	.3069	5.382	158.41	.3054
280	6.960	160.14	.3124	6.376	160.12	.3107	5.881	160.09	.3091	5.458	160.06	.3077
290	7.056	161.81	.3147	6.464	161.79	.3130	5.963	161.76	.3114	5.533	161.73	.3099
300	7.152	163.49	0.3169	6.552	163.47	0.3152	6.044	163.44	0.3136	5.609	163.41	0.3122
310	7.248	165.19	0.3191	6.640	165.16	0.3174	6.126	165.13	.3158	5.685	165.11	.3144
320	.....	.....	.....	.....	.....	.....	6.207	166.85	0.3180	5.761	166.83	0.3166

TABLE 2A-15. PROPERTIES OF SUPERHEATED VAPOR, FREON 21 (*Continued*)

Temp. °F.	Abs. Pressure 16 lb./in.² Gage Pressure 1.3 lb./in.² (Sat'n. Temp. 52.0°F.)			Abs. Pressure 18 lb./in.² Gage Pressure 3.3 lb./in.² (Sat'n. Temp. 57.6°F.)			Abs. Pressure 20 lb./in.² Gage Pressure 5.3 lb./in.² (Sat'n. Temp. 62.8°F.)			Abs. Pressure 22 lb./in.² Gage Pressure 7.3 lb./in.² (Sat'n. Temp. 67.5°F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(at sat'n)	(3.239)	(125.64)	(0.2499)	(2.902)	(126.31)	(0.2490)	(2.630)	(126.94)	(0.2482)	(2.406)	(127.49)	(0.2475)
60	3.293	126.73	0.2520	2.916	126.64	0.2496	.....	.....	.....	.....	.....	.....
70	3.361	128.10	.2546	2.977	128.02	.2522	2.670	127.94	0.2501	2.419	127.84	0.2481
80	3.429	129.49	.2572	3.038	129.41	.2548	2.725	129.33	.2527	2.469	129.24	.2507
90	3.496	130.89	.2597	3.098	130.81	.2574	2.780	130.73	.2552	2.519	130.64	.2533
100	3.564	132.30	0.2623	3.159	132.22	0.2599	2.834	132.14	0.2578	2.569	132.06	0.2558
110	3.632	133.72	.2648	3.219	133.65	.2624	2.889	133.56	.2603	2.619	133.49	.2584
120	3.699	135.16	.2673	3.279	135.08	.2649	2.943	135.00	.2628	2.668	134.93	.2609
130	3.766	136.60	.2698	3.339	136.52	.2674	2.998	136.45	.2653	2.718	136.38	.2634
140	3.834	138.06	.2722	3.399	137.99	.2699	3.052	137.91	.2678	2.768	137.84	.2659
150	3.901	139.54	0.2747	3.459	139.47	0.2723	3.106	139.39	0.2702	2.817	139.32	0.2683
160	3.968	141.04	.2771	3.519	140.97	.2748	3.160	140.90	.2727	2.866	140.83	.2708
170	4.035	142.55	.2795	3.579	142.48	.2772	3.214	142.41	.2751	2.916	142.35	.2732
180	4.102	144.07	.2819	3.639	144.00	.2796	3.268	143.93	.2775	2.965	143.88	.2756
190	4.169	145.60	.2843	3.699	145.53	.2820	3.322	145.46	.2799	3.014	145.41	.2780
200	4.236	147.14	0.2867	3.758	147.07	0.2843	3.376	147.01	0.2822	3.063	146.95	0.2803
210	4.303	148.70	.2890	3.818	148.64	.2867	3.430	148.58	.2846	3.112	148.51	.2827
220	4.370	150.28	.2913	3.877	150.22	.2890	3.484	150.16	.2869	3.161	150.09	.2850
230	4.436	151.87	.2937	3.937	151.81	.2913	3.537	151.75	.2892	3.210	151.68	.2873
240	4.503	153.47	.2960	3.996	153.41	.2936	3.591	153.36	.2915	3.259	153.28	.2897
250	4.570	155.09	0.2983	4.056	155.03	0.2959	3.645	154.97	0.2938	3.308	154.90	0.2920
260	4.636	156.71	.3005	4.115	156.65	.2982	3.698	156.60	.2961	3.357	156.53	.2942
270	4.703	158.35	.3028	4.175	158.29	.3005	3.752	158.24	.2984	3.406	158.18	.2965
280	4.769	160.00	.3051	4.234	159.95	.3027	3.805	159.90	.3007	3.455	159.84	.2988
290	4.836	161.67	.3073	4.293	161.63	.3050	3.859	161.57	.3029	3.503	161.52	.3010
300	4.902	163.36	0.3095	4.352	163.31	0.3072	3.912	163.25	0.3051	3.552	163.20	0.3033
310	4.969	165.06	.3118	4.411	165.01	.3094	3.965	164.95	.3074	3.601	164.90	.3055
320	5.035	166.77	.3140	4.470	166.73	.3117	4.019	166.67	.3096	3.649	166.62	.3077
330	5.101	168.50	0.3162	4.529	168.45	0.3139	4.072	168.40	.3118	3.698	168.35	.3099
340	.....	.....	.....	.....	.....	.....	4.125	170.14	0.3140	3.746	170.09	0.3121

Temp. °F.	Abs. Pressure 24 lb./in.² Gage Pressure 9.3 lb./in.² (Sat'n. Temp. 72.0°F.)			Abs. Pressure 26 lb./in.² Gage Pressure 11.3 lb./in.² (Sat'n. Temp. 76.2°F.)			Abs. Pressure 28 lb./in.² Gage Pressure 13.3 lb./in.² (Sat'n. Temp. 80.1°F.)			Abs. Pressure 30 lb./in.² Gage Pressure 15.3 lb./in² (Sat'n. Temp. 83.8°F.)		
(at sat'n)	(2.218)	(128.03)	(0.2469)	(2.058)	(128.54)	(0.2463)	(1.920)	(128.98)	(0.2458)	(1.800)	(129.42)	(0.2453)
80	2.256	129.15	0.2489	2.075	129.07	0.2473	.....	.....	.....	.....	.....	.....
90	2.302	130.55	.2515	2.117	130.47	.2499	1.960	130.38	0.2483	1.823	130.30	0.2469
100	2.347	131.97	0.2541	2.160	131.89	0.2524	2.000	131.81	0.2509	1.860	131.72	0.2495
110	2.393	133.40	.2566	2.203	133.32	.2550	2.039	133.24	.2535	1.898	133.16	.2520
120	2.439	134.85	.2591	2.245	134.77	.2575	2.079	134.69	.2560	1.935	134.61	.2546
130	2.485	136.30	.2616	2.288	136.22	.2600	2.119	136.14	.2585	1.972	136.06	.2571
140	2.530	137.77	.2641	2.330	137.69	.2625	2.158	137.61	.2610	2.009	137.53	.2596
150	2.576	139.26	0.2666	2.372	139.17	0.2649	2.197	139.10	0.2634	2.046	139.02	0.2620
160	2.622	140.76	.2690	2.414	140.68	.2674	2.237	140.61	.2659	2.083	140.53	.2645
170	2.667	142.28	.2714	2.456	142.20	.2698	2.276	142.13	.2683	2.119	142.06	.2669
180	2.712	143.80	.2738	2.498	143.73	.2722	2.315	143.66	.2707	2.156	143.59	.2693
190	2.757	145.33	.2762	2.540	145.26	.2746	2.354	145.20	.2731	2.193	145.13	.2717
200	2.803	146.88	0.2786	2.582	146.81	0.2770	2.393	146.75	0.2755	2.229	146.68	0.2741
210	2.848	148.45	.2809	2.624	148.38	.2793	2.432	148.32	.2778	2.266	148.25	.2764
220	2.893	150.03	.2833	2.666	149.97	.2817	2.471	149.91	.2802	2.302	149.84	.2788
230	2.938	151.62	.2856	2.707	151.56	.2840	2.510	151.50	.2825	2.338	151.44	.2811
240	2.983	153.23	.2879	2.749	153.17	.2863	2.548	153.11	.2848	2.375	153.05	.2834
250	3.028	154.85	0.2902	2.791	154.79	0.2886	2.587	154.74	0.2871	2.411	154.68	0.2857
260	3.073	156.48	.2925	2.832	156.42	.2909	2.626	156.37	.2894	2.447	156.31	.2880
270	3.118	158.12	.2948	2.874	158.07	.2932	2.665	158.01	.2917	2.483	157.95	.2903
280	3.162	159.78	.2970	2.915	159.73	.2954	2.703	159.67	.2940	2.520	159.61	.2926
290	3.207	161.46	.2993	2.957	161.40	.2977	2.742	161.35	.2962	2.556	161.30	.2948
300	3.252	163.15	0.3015	2.998	163.09	0.2999	2.780	163.04	0.2985	2.592	162.99	0.2971
310	3.297	164.85	.3038	3.039	164.79	.3022	2.819	164.74	.3007	2.628	164.69	.2993
320	3.341	166.57	.3060	3.081	166.51	.3044	2.857	166.46	.3029	2.664	166.41	.3015
330	3.386	168.30	.3082	3.122	168.24	.3066	2.896	168.19	.3051	2.700	168.14	.3037
340	3.431	170.04	.3104	3.163	169.98	.3088	2.934	169.93	.3073	2.736	169.89	.3059
350	3.475	171.78	0.3125	3.205	171.73	0.3110	2.973	171.68	0.3095	2.772	171.64	0.3081
360	.....	.....	.....	.....	.....	.....	3.011	173.46	0.3117	2.807	173.41	0.3108

TABLE 2A-15. PROPERTIES OF SUPERHEATED VAPOR, FREON 21 (*Continued*)

Temp. °F.	Abs. Pressure 32 lb./in.² Gage Pressure 17.3 lb./in.² (Sat'n. Temp. 87.3°F.)			Abs. Pressure 34 lb /in.² Gage Pressure 19.3 lb /in.² (Sat'n. Temp. 90.7°F.)			Abs. Pressure 36 lb./in.² Gage Pressure 21 3 lb /in.² (Sat'n. Temp. 93.9°F.)			Abs. Pressure 38 lb./in.² Gage Pressure 23.3 lb./in.² (Sat'n. Temp. 97.0°F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(at sat'n)	(1 694)	(129 83)	(0.2449)	(1.600)	(130 22)	(0 2445)	(1 516)	(130 60)	(0 2441)	(1.441)	(130.96)	(0.2438)
90	1.703	130.21	0.2456	.....	.....	.....	.....	.....	.....	.....	.....	.....
100	1.739	131.64	0.2481	1.631	131.55	0.2469	1.535	131.47	0.2457	1.450	131.38	0.2445
110	1.774	133.08	.2507	1.664	132.99	.2494	1.567	132.91	.2482	1.480	132.82	.2471
120	1.809	134.53	.2532	1.697	134.44	.2520	1.598	134.36	.2508	1.510	134.38	.2496
130	1.844	135.99	.2557	1.730	135.91	.2545	1.630	135.83	.2533	1.540	135.75	.2522
140	1.878	137.46	.2582	1.763	137.38	.2570	1.661	137.30	.2558	1.569	137.23	.2547
150	1.913	138.95	0.2607	1.796	138.87	0.2594	1.692	138.80	0.2583	1.599	138.73	0.2571
160	1.948	140.46	.2632	1.829	140.39	.2619	1.723	140.32	.2607	1.629	140.25	.2596
170	1.982	141.99	.2656	1.862	141.92	.2643	1.754	141.85	.2632	1.658	141.78	.2620
180	2.017	143.52	.2680	1.894	143.45	.2668	1.785	143.38	.2656	1.687	143.31	.2645
190	2.051	145.06	.2704	1.927	144.99	.2692	1.816	144.92	.2680	1.717	144,85	.2669
200	2.086	146.61	0.2728	1.959	146.55	0.2715	1.847	146.48	0.2704	1.746	146.41	0.2693
210	2.120	148.19	.2751	1.992	148.13	.2739	1.878	148.06	.2727	1.775	147.99	.2716
220	2.154	149.78	.2775	2.024	149.72	.2763	1.908	149.65	.2751	1.804	149.59	.2740
230	2.189	151.38	.2798	2.056	151.32	.2786	1.939	151.25	.2774	1.834	151.19	.2763
240	2.223	152.99	.2821	2.089	152.93	.2809	1.969	152.87	.2798	1.863	152.80	.2787
250	2.257	154.62	0.2844	2.121	154.56	0.2832	2.000	154.50	0.2821	1.892	154.43	0.2810
260	2.291	156.25	.2867	2.153	156.19	.2855	2.030	156.13	.2844	1.920	156.07	.2833
270	2.325	157.90	.2890	2.185	157.84	.2878	2.061	157.78	.2866	1.949	157.72	.2855
280	2.359	159.56	.2913	2.217	159.51	.2901	2.091	159.45	.2889	1.978	159.38	.2878
290	2.393	161.24	.2935	2.249	161.19	.2923	2.121	161.13	.2912	2.007	161.07	.2901
300	2.427	162.93	0.2958	2.281	162.88	0.2946	2.152	162.82	0.2934	2.036	162.77	0.2923
310	2.461	164.64	.2980	2.313	164.59	.2968	2.182	164.53	.2956	2.065	164.48	.2946
320	2.494	166.36	.3002	2.345	166.31	.2990	2.212	166.26	.2979	2.093	166.20	.2968
330	2.528	168.09	.3024	2.377	168.04	.3012	2.242	167.99	.3001	2.122	167.94	.2990
340	2.562	169.84	.3046	2.409	169.79	.3034	2.272	169.74	.3023	2.150	169.69	.3012
350	2 596	171.59	0.3068	2.440	171.54	0.3056	2.303	171.49	0.3045	2.179	171.45	0.3034
360	2.629	173.36	0.3090	2.472	173.31	.3078	2.333	173.26	.3067	2.208	173.22	.3056
370	.....	.....	.....	2.504	175.10	0.3100	2.363	175.06	0.3088	2.236	175.01	0.3077

Temp °F.	Abs. Pressure 40 lb./in.² Gage Pressure 25.3 lb./in.² (Sat'n. Temp. 99.9°F.)			Abs. Pressure 45 lb./in.² Gage Pressure 30.3 lb./in.² (Sat'n. Temp. 106.9°F.)			Abs. Pressure 50 lb./in.² Gage Pressure 35.3 lb./in.² (Sat'n. Temp. 113.3°F.)			Abs. Pressure 55 lb./in.² Gage Pressure 40.3 lb./in.² (Sat'n. Temp. 119.1°F.)		
(at sat'n)	(1.373)	(131.28)	(0.2435)	(1.228)	(132.07)	(0.2427)	(1.111)	(132.79)	(0.2421)	(1.014)	(133.43)	(0.2415)
100	1.373	131.29	0.2435	.....	.....	.....	.....	.....	.....	.....	.....	.....
110	1.402	132.74	.2460	1.236	132.52	0.2435	.....	.....	.....	.....	.....	.....
120	1.430	134.20	.2486	1.262	133.99	.2460	1.127	133.78	0.2438	1.016	133.56	0.2417
130	1.459	135.67	.2511	1.287	135.47	.2486	1.150	135.26	.2463	1.038	135.05	.2442
140	1.487	137.15	.2536	1.313	136.95	.2511	1.173	136.75	.2488	1.059	136.55	.2468
150	1.515	138.65	0.2561	1.338	138.46	0.2536	1.197	138.26	0.2513	1.080	138.07	0.2493
160	1.543	140.17	.2585	1.363	139.99	.2561	1.220	139.79	.2538	1.102	139.60	.2518
170	1.572	141.70	.2610	1.389	141.52	.2585	1.243	141.33	.2563	1.123	141.14	.2543
180	1.600	143.24	.2634	1.414	143.06	.2610	1.265	142.88	.2587	1.144	142.70	.2567
190	1.628	144.79	.2658	1.439	144.62	.2634	1.288	144.43	.2612	1.165	144.26	.2591
200	1.656	146.35	0.2682	1.464	146.18	0.2658	1.311	146.00	0.2636	1.186	145.83	0.2615
210	1.683	147.93	.2706	1.489	147.76	.2681	1.334	147.59	.2659	1.206	147.42	.2639
220	1.711	149.52	.2729	1.514	149.36	.2705	1.356	149.19	.2683	1.227	149.03	.2663
230	1.739	151.13	.2753	1.539	150.97	.2729	1.379	150.80	.2707	1.248	150.64	.2687
240	1.767	152.75	.2776	1.564	152.59	.2752	1.401	152.42	.2730	1.269	152.26	.2710
250	1.794	154.38	0.2799	1.588	154.22	0.2775	1.424	154.06	0.2753	1.289	153.90	0.2733
260	1.822	156.01	.2822	1.613	155.86	.2798	1.446	155.71	.2776	1.310	155.56	.2757
270	1.849	157.66	.2845	1.638	157.52	.2821	1.469	157.37	.2799	1.330	157.23	.2780
280	1.877	159.33	.2868	1.662	159.19	.2844	1.491	159.05	.2822	1.351	158.91	.2802
290	1.904	161.02	.2890	1.687	160.88	.2866	1.513	160.74	.2845	1.371	160.60	.2825
300	1.932	162.72	0.2913	1.712	162.58	0.2889	1.535	162.44	0.2867	1.391	162.30	0.2848
310	1.959	164.43	.2935	1.736	164.29	.2911	1.558	164.16	.2890	1.411	164.02	.2870
320	1.986	166.15	.2957	1.760	166.02	.2934	1.580	165.89	.2912	1.432	165.76	.2893
330	2.014	167.89	.2980	1.785	167.76	.2956	1.602	167.63	.2934	1.452	167.50	.2915
340	2.041	169.64	.3002	1.809	169.51	.2978	1.624	169.38	.2956	1.472	169.25	.2937
350	2.068	171.40	0.3024	1.833	171.27	0.3000	1.646	171.14	0.2978	1.492	171.02	0.2959
360	2.095	173.17	.3045	1.858	173.05	.3022	1.668	172.92	.3000	1.512	172.80	.2981
370	2.122	174.96	0.3067	1.882	174.85	.3043	1.690	174.72	.3022	1.532	174.59	.3003
380	.....	.....	.....	1.906	176.65	.3065	1.712	176.52	.3044	1.552	176.40	.3024
390	.....	.....	.....	1.930	178.47	.3087	1.734	178.34	0.3065	1.572	178.23	.3046
400	.....	.....	.....	.....	.....	.....	.....	.....	.....	1.592	180.08	0.3067

TABLE 2A-15. PROPERTIES OF SUPERHEATED VAPOR, FREON 21 (*Continued*)

Temp °F	Abs. Pressure 60 lb./in.² Gage Pressure 45.3 lb./in.² (Sat'n. Temp. 124.7°F.)			Abs. Pressure 70 lb./in.² Gage Pressure 55.3 lb./in.² (Sat'n. Temp. 134.7°F.)			Abs. Pressure 80 lb./in.² Gage Pressure 65.3 lb./in.² (Sat'n. Temp. 143.8°F.)		
t	V	H	S	V	H	S	V	H	S
(at sat'n)	(0.9333)	(134.03)	(0.2410)	(0.8045)	(135.10)	(0.2401)	(0.7069)	(136.06)	(0.2393)
130	0.9439	134.83	0.2423	.....	.....	.....	.....	.....	.....
140	0.9639	136.34	.2449	0.8137	135.91	0.2414	.....	.....	.....
150	0.9836	137.86	0.2474	0.8312	137.45	0.2440	0.7167	137.01	0.2409
160	1.003	139.40	.2499	.8486	139.01	.2465	.7321	138.58	.2435
170	1.023	140.95	.2524	.8658	140.57	.2490	.7476	140.16	.2460
180	1.042	142.51	.2548	.8828	142.13	.2515	.7629	141.74	.2485
190	1.062	144.07	.2573	.8998	143.71	.2539	.7781	143.33	.2509
200	1.081	145.65	0.2597	0.9168	145.30	0.2564	0.7933	144.93	0.2534
210	1.100	147.25	.2621	.9336	146.90	.2588	.8083	146.54	.2558
220	1.120	148.86	.2645	.9504	148.52	.2612	.8233	148.17	.2582
230	1.139	150.48	.2668	.9671	150.15	.2635	.8382	149.81	.2606
240	1.158	152.11	.2692	0.9837	151.79	.2659	.8530	151.46	.2630
250	1.177	153.76	0.2715	1.000	153.44	0.2682	0.8678	153.12	0.2654
260	1.196	155.41	.2738	1.017	155.10	.2706	.8825	154.78	.2677
270	1.215	157.08	.2761	1.033	156.77	.2729	.8971	156.46	.2700
280	1.234	158.76	.2784	1.050	158.45	.2752	.9117	158.16	.2723
290	1.252	160.45	.2807	1.066	160.16	.2775	.9262	159.87	.2746
300	1.271	162.16	0.2830	1.082	161.88	0.2797	0.9406	161.59	0.2769
310	1.290	163.88	.2852	1.099	163.61	.2820	.9550	163.32	.2792
320	1.309	165.62	.2875	1.115	165.35	.2842	.9694	165.07	.2814
330	1.327	167.36	.2897	1.131	167.10	.2865	.9838	166.83	.2837
340	1.346	169.12	.2919	1.147	168.86	.2887	0.9981	168.60	.2859
350	1.364	170.89	0.2941	1.163	170.63	0.2909	1.012	170.38	0.2881
360	1.383	172.67	.2963	1.179	172.42	.2931	1.027	172.17	.2903
370	1.401	174.47	.2985	1.195	174.23	.2953	1.041	173.98	.2925
380	1.420	176.28	.3007	1.211	176.04	.2975	1.055	175.80	.2947
390	1.438	178.11	.3028	1.227	177.87	.2996	1.069	177.64	.2969
400	1.457	179.96	0.3050	1.243	179.73	0.3018	1.083	179.50	0.2990

Temp °F.	Abs. Pressure 90 lb./in.² Gage Pressure 75.3 lb./in.² (Sat'n Temp. 152.0°F.)			Abs. Pressure 100 lb./in.² Gage Pressure 85.3 lb./in.² (Sat'n. Temp. 159.6°F.)			Abs. Pressure 110 lb./in.² Gage Pressure 95.3 lb./in.² (Sat'n. Temp. 166.6°F.)		
(at sat'n)	(0.6301)	(136.91)	(0.2387)	(0.5680)	(137.66)	(0.2381)	(0.5167)	(138.32)	(0.2376)
160	0.6414	138.17	0.2407	0.5685	137.72	0.2382	.....	.....	.....
170	.6555	139.75	.2433	.5815	139.32	.2408	0.5209	138.87	0.2385
180	.6695	141.34	.2458	.5945	140.92	.2433	.5330	140.49	.2410
190	.6834	142.94	.2483	.6073	142.53	.2458	.5449	142.12	.2435
200	0.6972	144.55	0.2507	0.6200	144.16	0.2483	0.5567	143.75	0.2460
210	.7108	146.17	.2532	.6326	145.80	.2508	.5684	145.40	.2485
220	.7244	147.81	.2556	.6450	147.45	.2532	.5801	147.07	.2510
230	.7379	149.46	.2580	.6574	149.10	.2556	.5916	148.74	.2534
240	.7513	151.12	.2604	.6698	150.76	.2580	.6030	150.41	.2558
250	0.7646	152.79	0.2628	0.6820	152.44	0.2604	0.6143	152.09	0.2582
260	.7779	154.46	.2651	.6942	154.13	.2628	.6256	153.79	.2606
270	.7912	156.15	.2675	.7063	155.83	.2651	.6368	155.50	.2630
280	.8043	157.85	.2698	.7183	157.54	.2674	.6479	157.22	.2653
290	.8174	159.57	.2721	.7303	159.26	.2698	.6590	158.96	.2676
300	0.8304	161.30	0.2744	0.7423	161.00	0.2721	0.6700	160.70	0.2699
310	.8434	163.04	.2766	.7542	162.75	.2743	.6810	162.45	.2722
320	.8564	164.79	.2789	.7660	164.51	.2766	.6919	164.22	.2745
330	.8693	166.55	.2812	.7777	166.28	.2789	.7027	166.00	.2768
340	.8822	168.33	.2834	.7894	168.06	.2811	.7135	167.79	.2790
350	0.8950	170.11	0.2856	0.8011	169.85	0.2833	0.7243	169.58	0.2813
360	.9078	171.91	.2878	.8128	171.66	.2856	.7350	171.89	.2835
370	.9206	173.73	.2900	.8244	173.48	.2878	.7457	173.22	.2857
380	.9333	175.55	.2922	.8360	175.31	.2900	.7563	175.06	.2879
390	.9460	177.39	.2944	.8475	177.16	.2922	.7669	176.91	.2901
400	0.9586	179.26	0.2966	0.8590	179.02	0.2943	0.7775	178.78	0.2923

MONOCHLORODIFLUOROMETHANE, FREON 22

TABLE 2A-16. PROPERTIES OF SATURATED VAPOR

Temp., °F. t	Pressure		Volume		Density		Enthalpy from −40° F.			Entropy	
	Absolute, lbs./in.² p	Gage, lbs./in.² $g.p.$	Liquid, ft.³/lb. v_f	Vapor, ft.³/lb. v_g	Liquid, lbs./ft.³ $1/v_f$	Vapor, lbs./ft.³ $1/v_g$	Liquid, Btu./lb. h_f	Latent, Btu./lb. h_{fg}	Vapor, Btu./lb. h_g	Liquid, Btu., lb. °F. s_f	Vapor, Btu./lb. °F. s_g
−155	0.19901	29.51 *	0.0102	188.13	97.67	0.0053156	−29.05	115.85	86.80	−0.08075	0.29958
−150	0.26049	29.39 *	0.0103	146.06	97.33	0.0068467	−27.77	115.15	87.38	−0.07670	0.29523
−145	.33754	29.23 *	.0103	114.51	96.99	.0087329	−26.50	114.46	87.96	− .07265	.29118
−140	.43323	29.04 *	.0103	90.613	96.63	.011036	−25.23	113.78	88.55	− .06865	.28736
−135	.55106	28.80 *	.0104	72.327	96.27	.013826	−23.97	113.10	89.13	− .06471	.28372
−130	.69492	28.51 *	.0104	58.214	95.91	.017178	−22.71	112.43	89.72	− .06085	.28026
−125	0.86922	28.15 *	0.0105	47.226	95.53	0.021175	−21.45	111.76	90.31	−0.05706	0.27695
−120	1.0788	27.72 *	.0105	38.600	95.15	.025907	−20.20	111.10	90.90	− .05335	.27380
−115	1.3291	27.21 *	.0106	31.773	94.76	.031473	−18.96	110.45	91.49	− .04970	.27082
−110	1.6261	26.61 *	.0106	26.329	94.37	.037981	−17.71	109.80	92.09	− .04609	.26798
−105	1.9760	25.90 *	.0106	21.960	93.97	.045538	−16.46	109.15	92.69	− .04254	.26527
−100	2.3861	25.06 *	0.0107	18.426	93.56	0.054272	−15.21	108.50	93.29	−0.03903	0.26269
− 95	2.8649	24.09 *	.0107	15.544	93.14	.064333	−13.96	107.85	93.89	− .03557	.26023
− 90	3.4173	22.96 *	.0108	13.196	92.72	.075783	−12.71	107.20	94.49	− .03216	.25788
− 85	4.0554	21.67 *	.0108	11.256	92.29	.088843	−11.45	106.55	95.10	− .02881	.25563
− 80	4.7871	20.18 *	.0109	9.6497	91.85	.10363	−10.20	105.90	95.70	− .02551	.25347
− 75	5.6224	18.48 *	0.0109	8.3112	91.41	0.12032	− 8.94	105.24	96.30	−0.02224	0.25139
− 70	6.5711	16.55 *	.0110	7.1917	90.96	.13905	− 7.67	104.57	96.90	− .01899	.24941
− 65	7.6456	14.36 *	.0110	6.2488	90.50	.16003	− 6.41	103.91	97.50	− .01576	.24757
− 60	8.8562	11.89 *	.0111	5.4520	90.03	.18342	− 5.14	103.24	98.10	− .01256	.24580
− 55	10.224	9.11 *	.0112	4.7710	89.56	.20960	− 3.85	102.55	98.70	− .00939	.24407

− 50	11.744	6.02 *	0.0112	4.1948	89.08	0.23839	− 2.56	101.86	99.30	−0.00623	0.24245
− 45	13.428	2.59 *	.0113	3.7038	88.59	.26999	− 1.27	101.16	99.89	− .00311	.24088
− 40	15.309	0.609	.0114	3.2787	88.10	.30500	0.02	100.46	100.48	0.00000	.23942
− 35	17.391	2.691	.0114	2.9116	87 60	.34345	1.33	99.74	101.07	.00309	.23799
− 30	19.689	4.989	.0115	2.5936	87.09	.38557	2.64	99.01	101.65	.00616	.23663
− 25	22.217	7.517	0.0116	2.3170	86.58	0.43159	3.97	98.26	102.23	0.00922	0.23531
− 20	24.992	10.292	.0116	2.0755	86.06	.48181	5.31	97.50	102.81	.01227	.23406
− 15	28.031	13.331	.0117	1.8639	85.53	.53650	6.66	96.72	103.38	.01531	.23285
− 10	31.344	16.644	.0118	1.6783	84.99	.59583	8.01	95.93	103.94	.01833	.23170
− 5	34.951	20.251	.0118	1.5148	84.45	.66015	9.37	95.13	104.50	.02135	.23061
0	38.870	24.170	0.0119	1 3702	83.90	0.72980	10.74	94.30	105.04	0.02435	0.22953
5	43.118	28.418	.0120	1.2421	83.34	.80510	12.13	93.45	105.58	.02735	.22849
10	47.66	32.96	.012081	1.1295	82.778	.88532	12.89	93.02	105.91	.02884	.22692
20	58.00	43.30	.012250	0.93624	81.630	1.0683	15.68	91.27	106.95	.03468	.22498
30	69.97	55.27	.012430	.78125	80.453	1.2800	18.55	89.40	107.95	.04054	.22314
40	83.72	69.02	0.012619	0.65591	79.248	1.5246	21.52	87.39	108.91	0.04642	0.22134
50	99.40	84.70	.012818	.55371	78.015	1.8060	24.55	85.25	109.80	.05235	.21964
60	117.2	102.5	.013029	.46951	76.753	2.1299	27.65	82.95	110.60	.05833	.21797
70	137.2	122.5	.013251	.40000	75.464	2.5000	30.81	80.50	111.31	.06436	.21636
80	159.7	145.0	.013487	.34174	74.148	2.9262	34.09	77.86	111.95	.07035	.21469
90	184.8	170.1	0.013735	0.29284	72.808	3.4148	37.43	75.06	112.49	0.07630	0.21281
100	212.6	197.9	.014015	.25169	71.352	3.9731	40.80	72.08	112.88	.08221	.21102
110	243.4	228.7	.014331	.21673	69.781	4.6140	44.17	68.94	113.11	.08810	.20913
120	277.3	262.6	.014685	.18709	68.096	5.3451	47.67	65.67	113.34	.09398	.20728

Note: Values above line—February 27, 1942. Values below line—August 14, 1941.

* Inches mercury below one atmosphere.

TABLE 2A-17. PROPERTIES OF SUPERHEATED VAPOR, FREON 22

Temp., °F.	Abs. Pressure .25 lb./in.^{2} Gage Pressure 29.41 in. Vac. (Sat'n. Temp. −150.9° F.)			Abs. Pressure .30 lb./in.^{2} Gage Pressure 29.31 in. Vac. (Sat'n. Temp. −147.4° F.)			Abs. Pressure .35 lb./in.^{2} Gage Pressure 29.21 in. Vac. (Sat'n. Temp. −144.3° F.)		
t	*v*	*h*	*s*	*v*	*h*	*s*	*v*	*h*	*s*
(at sat'n.)	*(151.75)*	*(87.28)*	*(0.29597)*	*(127.87)*	*(87.68)*	*(0.29316)*	*(110.67)*	*(88.04)*	*(0.29068)*
−150	152.19	87.38	0.29620	.	. . .		..	..	......
−140	157.12	88.55	.29993	130.91	88.55	0.29578	112.19	88.55	0.29226
−130	162.04	89.74	.30360	135.01	89.74	.29945	115.71	89.74	.29593
−120	166.96	90.95	.30720	139.12	90.94	.30305	119.23	90.94	.29953
−110	171.89	92.16	.31074	143.22	92.16	.30659	122.75	92.16	.30307
−100	176.81	93.40	0.31421	147.33	93 39	0.31006	126.26	93.39	0.30654
− 90	181.74	94.64	.31762	151.43	94.64	.31347	129.78	94.64	.30995
− 80	186.66	95.91	.32098	155.53	95.90	.31683	133.30	95.90	.31331
− 70	191.59	97.18	.32429	159 64	97 18	.32014	136.82	97.18	.31662
− 60	196.51	98.48	.32756	163.74	98.47	.32341	140.33	98.47	.31989
− 50	201.43	99.78	0.33078	167.84	99.78	0.32663	143.85	99.78	0.32312
− 40	206.35	101.10	.33397	171.95	101.10	.32982	147.37	101.10	.32631
− 30	211.28	102.44	.33713	176.05	102.44	.33297	150.89	102.43	.32946
− 20	216.20	103.79	.34025	180.15	103.79	.33609	154.40	103.79	.33258
− 10	221.12	105.16	.34333	184.25	105.15	.33917	157.92	105.15	.33566
0	226.04	106.54	0.34638	188.36	106.53	0.34222	161.44	106.53	0.33871
10	230.97	107.93	.34939	192.46	107.93	.34523	164.96	107.93	.34172
20	235.89	109.34	.35236	196.56	109.34	.34821	168.47	109.34	.34470
30	240.81	110.77	.35530	200.66	110.77	.35115	171.99	110.76	.34764
40	245.73	112.21	.35821	204.76	112.20	.35406	175.50	112.20	.35055
50	250.66	113.66	0.36109	208.87	113.66	0.35694	179.02	113.66	0.35343
60	255.58	115.13	.36394	212.97	115.13	.35979	182.54	115.13	.35628
70	260.50	116.61	.36677	217.07	116.61	.36262	186.05	116.61	.35911
80	265.42	118.11	.36957	221.17	118.11	.36542	189.57	118.11	.36191
90	270.34	119.63	.37235	225.28	119.62	36820	193.09	119.62	.36469
100	275.27	121.15	0.37511	229.38	121.15	0.37096	196.60	121.15	0.36745
110	280.19	122.70	.37785	233.48	122.70	.37370	200.12	122.70	.37019
120	285.11	124.26	.38056	237.58	124.25	.37641	203.63	124.25	.37290
130	290.03	125.83	.38325	241.68	125.83	.37910	207.15	125.83	.37559
140	294.95	127.42	.38592	245.78	127.42	.38177	210.66	127.41	.37826
150	299.87	129.02	0.38857	249.89	129.02	0.38442	214.18	129.02	0.38091
160	......	.	.	253.99	130.64	.38705	217.70	130.63	.38354

Table 2a–17. Properties of Superheated Vapor, Freon 22 (*Continued*)

Temp., °F.	Abs. Pressure .40 lb./in.^{2} Gage Pressure 29.11 in. Vac. (Sat'n. Temp. −141.7° F.)			Abs. Pressure .45 lb./in.^{2} Gage Pressure 29.00 in. Vac. (Sat'n. Temp. −139.3° F.)			Abs. Pressure .50 lb./in.^{2} Gage Pressure 28.90 in. Vac. (Sat'n. Temp. −137.2° F.)		
t	*v*	*h*	*s*	*v*	*h*	*s*	*v*	*h*	*s*
(at sat'n.)	(97.624)	(88.35)	(0.28869)	(87.420)	(88.63)	(0.28684)	(79.183)	(88.88)	(0.28530)
−140	98.149	88.55	0.28922		..	. .	. ... .	.....	....
−130	101.23	89.73	.29289	89.966	89.73	0.29021	80.956	89.73	0.28780
−120	104.31	90.94	.29649	92.704	90 94	.29381	83 421	90.93	.29140
−110	107.39	92.16	.30003	95.442	92.15	.29735	85.887	92.15	.29494
−100	110.47	93.39	0.30350	98.18	93.39	0.30082	88.351	93.38	0.29841
− 90	113.55	94.64	.30691	100.92	94.63	.30423	90.814	94.63	.30182
− 80	116.62	95.90	.31026	103 65	95.90	.30758	93.278	95.89	.30518
− 70	119.70	97.18	.31357	106 39	97 17	.31089	95.742	97.17	.30849
− 60	122.78	98.47	.31684	109.13	98.47	.31416	98 205	98.46	.31176
− 50	125.86	99.77	0.32007	111.86	99 77	0.31739	100.67	99.77	0.31499
− 40	128.94	101.10	.32326	114.60	101.09	.32058	103.13	101.09	.31818
− 30	132.01	102.43	.32641	117.34	102.43	.32373	105.60	102.43	.32133
− 20	135.09	103.78	.32953	120.07	103 78	.32685	108.06	103.78	.32445
− 10	138.17	105.15	.33262	122.81	105.15	.32993	110.52	105.15	.32753
0	141.25	106.53	0.33567	125.54	106.53	0.33298	112.98	106.53	0.33058
10	144.33	107.93	.33868	128.28	107 92	.33599	115.45	107.92	.33359
20	147.40	109.34	.34165	131.02	109.33	.33897	117.91	109.33	.33657
30	150.48	110.76	.34459	133.75	110.76	.34191	120.37	110.76	.33951
40	153.56	112.20	.34750	136.49	112.20	.34482	122.83	112.20	.34242
50	156.63	113.66	0.35038	139.22	113.65	0.34770	125.29	113.65	0.34530
60	159.71	115.12	.35323	141.96	115 12	.35055	127.76	115.12	.34815
70	162.79	116.61	.35606	144 69	116.61	.35338	130.22	116.61	.35098
80	165.87	118.11	.35887	147 43	118.11	.35618	132.68	118.11	.35378
90	168.94	119.62	.36165	150.16	119.62	.35896	135.14	119.62	.35656
100	172.02	121.15	0.36441	152.90	121.15	0.36172	137.60	121.15	0.35932
110	175.10	122.69	.36715	155.63	122.69	.36446	140.07	122.69	.36206
120	178.17	124.25	.36986	158.37	124 25	.36717	142.53	124.25	.36477
130	181.25	125.82	.37255	161.10	125.82	.36986	144.99	125.82	.36746
140	184.33	127.41	.37522	163.84	127.41	.37253	147.45	127.41	.37013
150	187.40	129.02	0.37787	166.57	129.01	0.53718	149.91	129.01	0.37278
160	190.48	130.63	.38050	169.31	130.63	.37781	152.37	130.63	.37541
170	......	......	.... .	172.04	132.26	.38042	154.83	132.26	.37802

TABLE 2A–17. PROPERTIES OF SUPERHEATED VAPOR, FREON 22 (*Continued*)

Temp., °F.	Abs. Pressure .55 lb./in.^{2} Gage Pressure 28.80 in. Vac. (Sat'n. Temp. −135.0° F.)			Abs. Pressure .60 lb./in.^{2} Gage Pressure 28.70 in. Vac. (Sat'n. Temp. −133.3° F.)			Abs. Pressure .65 lb./in.^{2} Gage Pressure 28.60 in. Vac. (Sat'n. Temp. −131.6° F.)		
t	*v*	*h*	*s*	*v*	*h*	*s*	*v*	*h*	*s*
(*at sat'n.*)	(*72.465*)	(*89.12*)	(*0.28375*)	(*66.765*)	(*89.33*)	(*0.28254*)	(*61.942*)	(*89.54*)	(*0.28134*)
−130	73.585	89.73	0.28563	67.443	89.72	0.28365	62.246	89.72	0.28182
−120	75.827	90.93	.28923	69.498	90.93	.28725	64.143	90.92	.28542
−110	78.068	92.15	.29277	71.553	92.15	.29079	66.040	92.14	.28896
−100	80.309	93.38	0.29624	73.608	93.38	0.29426	67.937	93.38	0.29243
− 90	82.549	94.63	.29965	75.661	94.63	.29767	69.832	94.62	.29584
− 80	84.789	95.89	.30300	77.714	95.89	.30102	71.728	95.89	.29920
− 70	87.029	97.17	.30631	79.767	97.17	.30433	73.624	97.16	.30251
− 60	89.269	98.46	.30958	81.821	98.46	.30760	75.520	98.46	.30578
− 50	91.509	99.77	0.31281	83.875	99.77	0.31083	77.416	99.76	0.30901
− 40	93.749	101.09	.31600	85.928	101.09	.31402	79.312	101.09	.31220
− 30	95.987	102.43	.31915	87.980	102.42	.31717	81.207	102.42	.31535
− 20	98.225	103.78	.32227	90.032	103.78	.32029	83.101	103.77	.31847
− 10	100.46	105.14	.32536	92.085	105.14	.32338	84.996	105.14	.32155
0	102.70	106.52	0.32841	94.138	106.52	0.32643	86.891	106.52	0.32460
10	104.94	107.92	.33142	96.191	107.92	.32944	88.786	107.92	.32761
20	107.18	109.33	.33440	98.244	109.33	.33242	90.681	109.33	.33059
30	109.42	110.76	.33734	100.30	110.75	.33536	92.575	110.75	.33353
40	111.66	112.20	.34025	102.35	112.19	.33827	94.469	112.19	.33644
50	113.90	113.65	0.34313	104.40	113.65	0.34115	96.364	113.65	0.33932
60	116.14	115.12	.34598	106.45	115.12	.34400	98.258	115.12	.34217
70	118.37	116.60	.34881	108.50	116.60	.34683	100.15	116.60	.34500
80	120.61	118.10	.35161	110.55	118.10	.34963	102.05	118.10	.34781
90	122.85	119.62	.35439	112.61	119.62	.35241	103.94	119.61	.35059
100	125.09	121.15	0.35715	114.66	121.14	0.35517	105.84	121.14	0.35335
110	127.33	122.69	.35989	116.71	122.69	.35791	107.73	122.69	.35609
120	129.56	124.25	.36260	118.76	124.25	.36062	109.62	124.24	.35880
130	131.80	125.82	.36529	120.81	125.82	.36331	111.52	125.82	.36149
140	134.04	127.41	.36796	122.87	127.41	.36598	113.41	127.41	.36416
150	136.28	129.01	0.37061	124.92	129.01	0.36863	115.30	129.01	0.36681
160	138.52	130.63	.37324	126.97	130.63	.37126	117.20	130.63	.36944
170	140.75	132.26	.37585	129.02	132.26	.37387	119.09	132.26	.37205

TABLE 2A-17. PROPERTIES OF SUPERHEATED VAPOR, FREON 22 (*Continued*)

Temp., °F.	Abs. Pressure .70 lb./in.² Gage Pressure 28.50 in. Vac. (Sat'n. Temp. −129.9° F.)			Abs. Pressure .75 lb./in.² Gage Pressure 28.39 in. Vac. (Sat'n. Temp. −128.4° F.)			Abs. Pressure .80 lb./in.² Gage Pressure 28.29 in. Vac. (Sat'n. Temp. −127.0° F.)		
t	*v*	*h*	*s*	*v*	*h*	*s*	*v*	*h*	*s*
(*at sat'n.*)	(*57.809*)	(*89.74*)	(*0.28016*)	(*54.193*)	(*89.91*)	(*0.27921*)	(*51.014*)	(*90.08*)	(*0.27826*)
−120	59.553	90.92	0.28373	55.575	90.92	0.28215	52.094	90.92	0.28068
−110	61.314	92.14	.28727	57.219	92.14	.28569	53.635	92.13	.28422
−100	63.076	93.37	0.29074	58.863	93.37	0.28916	55.177	93.37	0.28769
− 90	64.836	94.62	.29415	60.507	94.62	.29257	56.718	94.62	.29110
− 80	66.597	95.89	.29751	62.151	95.88	.29593	58.260	95.88	.29446
− 70	68.358	97.16	.30052	63.794	97.16	.29924	59.801	97.16	.29777
− 60	70.119	98.46	.30409	65.438	98.45	.30251	61.342	98.45	.30104
− 50	71.879	99.76	0.30732	67.081	99.76	0.30574	62.882	99.76	0.30427
− 40	73.639	101.08	.31051	68.725	101.08	.30893	64.423	101.08	.30746
− 30	75.399	102.42	.31366	70.367	102.42	.31209	65.964	102.42	.31062
− 20	77.159	103.77	.31678	72.009	103.77	.31521	67.504	103.77	.31374
− 10	78.919	105.14	.31986	73.653	105.14	.31829	69.044	105.13	.31682
0	80.679	106.52	0.32291	75.295	106.52	0.32134	70.584	106.52	0.31987
10	82.439	107.91	.32592	76.937	107.91	.32435	72.124	107.91	.32288
20	84.198	109.33	.32890	78.580	109.32	.32733	73.664	109.32	.32586
30	85.957	110.75	.33184	80.222	110.75	.33027	75.204	110.75	.32880
40	87.717	112.19	.33475	81.864	112.19	.33318	76.743	112.19	.33171
50	89.476	113.65	0.33763	83.506	113.64	0.33606	78.283	113.64	0.33459
60	91.234	115.11	.34048	85.148	115.11	.33891	79.822	115.11	.33744
70	92.994	116.60	.34331	86.790	116.60	.34174	81.362	116.60	.34027
80	94.754	118.10	.34612	88.432	118.10	.34455	82.901	118.10	.34307
90	96.513	119.61	.34890	90.074	119.61	.34733	84.441	119.61	.34585
100	98.271	121.14	0.35166	91.715	121.14	0.35009	85.980	121.14	0.34861
110	100.03	122.69	.35440	93.357	122.68	.35283	87.519	122.68	.35135
120	101.79	124.24	.35711	94.999	124.24	.35554	89.058	124.24	.35407
130	103.55	125.82	.35980	96.641	125.82	.35823	90.598	125.81	.35676
140	105.31	127.40	.36247	98.282	127.40	.36090	92.136	127.40	.35943
150	107.06	129.01	0.36512	99.924	129.01	0.36355	93.675	129.00	0.36208
160	108.82	130.62	.36775	101.56	130.62	.36618	95.214	130.62	.36471
170	110.58	132.26	.37036	103.21	132.26	.36879	96.754	132.25	.36732
180	112.34	133.90	.37295	104.85	133.90	.37138	98.292	133.90	.36991

TABLE 2A-17. PROPERTIES OF SUPERHEATED VAPOR, FREON 22 (*Continued*)

Temp., °F.	Abs. Pressure .90 lb./in.^{2} Gage Pressure 28.09 in. Vac. (Sat'n. Temp. −124.3° F.)			Abs. Pressure 1.00 lb./in.^{2} Gage Pressure 27.88 in. Vac. (Sat'n. Temp. −121.9° F.)			Abs. Pressure 1.25 lb./in.^{2} Gage Pressure 27.38 in. Vac. (Sat'n. Temp. −116.6° F.)		
t	*v*	*h*	*s*	*v*	*h*	*s*	*v*	*h*	*s*
(*at sat'n.*)	(*45.702*)	(*90.40*)	(*0.27649*)	(*41.416*)	(*90.68*)	(*0.27498*)	(*33.633*)	(*91.30*)	(*0.27176*)
−120	46.292	90.91	0.27799	41.651	90.90	0.27559	. . .	......	......
−110	47.663	92.13	.28153	42.885	92.12	.27913	34.286	92.11	0.27403
−100	49.034	93.36	0.28500	44.120	93.36	0.28260	35.273	93.35	0.27750
− 90	50.405	94.61	.28841	45.353	94.61	.28601	36.261	94.60	.28091
− 80	51.775	95.88	.29177	46.586	95.87	.28937	37.249	95.86	.28427
− 70	53.145	97.15	.29508	47.820	97.15	.29268	38.236	97.14	.28758
− 60	54.515	98.45	.29835	49.054	98.44	.29595	39.224	98.43	.29085
− 50	55.885	99.75	0.30158	50.287	99.75	0.29918	40.211	99.74	0.29408
− 40	57.256	101.08	.30477	51.521	101.07	.30237	41.199	101.06	.29727
− 30	58.625	102.41	.30793	52.753	102.41	.30553	42.186	102.40	.30043
− 20	59.994	103.76	.31105	53.986	103.76	.30865	43.172	103.75	.30355
− 10	61.363	105.13	.31413	55.219	105.13	.31173	44.159	105.12	.30664
0	62.732	106.51	0.31718	56.452	106.51	0.31478	45.145	106.50	0.30969
10	64.102	107.91	.32019	57.684	107.90	.31779	46.132	107.89	.31270
20	65.471	109.32	.32317	58.917	109.31	.32077	47.118	109.31	.31568
30	66.840	110.74	.32611	60.149	110.74	.32371	48.104	110.73	.31862
40	68.209	112.18	.32902	61.380	112.18	.32662	49.090	112.17	.32153
50	69.577	113.64	0.33190	62.613	113.64	0.32950	50.077	113.63	0.32441
60	70.945	115.11	.33475	63.844	115.10	.33235	51.062	115.09	.32726
70	72.314	116.59	.33758	65.076	116.59	.33518	52.048	116.58	.33009
80	73.683	118.09	.34039	66.308	118.09	.33799	53.034	118.08	.33290
90	75.051	119.61	.34317	67.540	119.60	.34077	54.020	119.60	.33568
100	76.420	121.14	0.34593	68.772	121.13	0.34353	55.005	121.12	0.33844
110	77.789	122.68	.34867	70.004	122.68	.34627	55.991	122.67	.34118
120	79.157	124.24	.35138	71.235	124.23	.34898	56.977	124.23	.34389
130	80.525	125.81	.35407	72.467	125.81	.35167	57.963	125.80	.34658
140	81.893	127.40	.35674	73.698	127.40	.35434	58.948	127.39	.34925
150	83.261	129.01	0.35939	74.930	129.01	0.35699	59.934	128.99	0.35190
160	84.630	130.62	.36202	76.161	130.62	.35962	60.919	130.61	.35453
170	85.998	132.25	.36463	77.393	132.25	.36223	61.904	132.24	.35714
180	87.366	133.90	.36722	78.624	133.90	.36482	62.889	133.89	.35973
190	.. ...	.. ...	. . .	. ..	.... .	.... .	63.875	135.55	.36230

TABLE 2A–17. PROPERTIES OF SUPERHEATED VAPOR, FREON 22 (*Continued*)

Temp., °F.	Abs. Pressure 1.50 lb./in.^{2} Gage Pressure 26.87 in. Vac. (Sat'n. Temp. −112.1° F.)			Abs. Pressure 1.75 lb./in.^{2} Gage Pressure 26.36 in. Vac. (Sat'n. Temp. −108.2° F.)			Abs. Pressure 2.0 lb./in.^{2} Gage Pressure 25.85 in Vac. (Sat'n. Temp. −104.7° F.)		
t	*v*	*h*	*s*	*v*	*h*	*s*	*v*	*h*	*s*
(at sat'n.)	*(23.379)*	*(91.84)*	*(0.26919)*	*(24.534)*	*(92.30)*	*(0.26702)*	*(21.713)*	*(92.73)*	*(0.26512)*
−110	28.552	92.10	0.26986	.	. . .	....	......	......	....
−100	29.376	93.33	0.27333	25.163	93.32	0.26980	22.004	93.31	0.26674
− 90	30.199	94.58	.27674	25.870	94.57	.27321	22.623	94.56	.27015
− 80	31.023	95.85	.28010	26.577	95.84	.27657	23.242	95.83	.27352
− 70	31.847	97.13	.28342	27.283	97.12	.27989	23.860	97.10	.27684
− 60	32.670	98.42	.28669	27.989	98.41	.28316	24.479	98.40	.28011
− 50	33.494	99.73	0.28992	28.696	99.72	0.28639	25.097	99.71	0.28334
− 40	34.317	101.05	.29311	29.402	101.04	.28958	25.715	101.03	.28653
− 30	35.140	102.39	.29627	30.107	102.38	.29274	26.333	102.37	.28969
− 20	35.963	103.74	.29939	30.813	103.73	.29586	26.951	103.72	.29281
− 10	36.785	105.11	.30247	31.518	105.10	.29895	27.569	105.09	.29590
0	37.607	106.49	0.30552	32 224	106.48	0.30200	28.186	106.47	0.29895
10	38.430	107.88	.30853	32.929	107.87	.30501	28.803	107.87	.30196
20	39.253	109.30	.31151	33.634	109.29	.30799	29.421	109.28	.30494
30	40.075	110.72	.31446	34.339	110 71	.31094	30.038	110.70	.30789
40	40.896	112.16	.31737	35.044	112.15	.31385	30.655	112.15	.31080
50	41.719	113.62	0.32025	35.749	113.61	0.31673	31.272	113.60	0.31368
60	42.541	115.08	.32310	36.454	115.08	.31958	31.889	115.07	.31653
70	43.363	116.57	.32593	37.159	116.57	.32241	32.506	116.56	.31936
80	44.184	118.07	.32874	37.863	118.07	.32522	33.122	118.06	.32217
90	45.006	119.59	.33152	38.568	119.58	.32800	33.739	119.57	.32495
100	45.828	121.12	0.33428	39.273	121.11	0.33076	34.356	121.10	0.32771
110	46.650	122.66	.33702	39.977	122.65	.33350	34.973	122.65	.33045
120	47.472	124.22	.33974	40.682	124.21	.33622	35.590	124.21	.33317
130	48.293	125.79	.34243	41.386	125.79	.33891	36.206	125.78	.33586
140	49.115	127.38	.34510	42.091	127.38	.34158	36.823	127.37	.33853
150	49.936	128.99	0.34775	42.795	128.98	0.34423	37.439	128.97	0.34118
160	50.757	130.60	.35038	43.499	130 60	.34686	38.056	130.59	.34381
170	51.579	132.24	.35299	44.203	132.23	.34947	38.672	132.22	.34643
180	52.400	133.88	.35558	44.908	133.88	.35207	39.288	133.87	.34903
190	53.221	135.55	.35816	45.612	135.54	.35465	39.905	135.53	.35161
200	......	......	. . .	46.316	137.22	0.35721	40.521	137.21	0.35417

TABLE 2A-17. PROPERTIES OF SUPERHEATED VAPOR, FREON 22 (*Continued*)

Temp., °F.	Abs. Pressure 2.5 lb./in.² Gage Pressure 24.83 in. Vac. (Sat'n. Temp. −98.8° F.)			Abs. Pressure 3.0 lb./in.² Gage Pressure 23.81 in. Vac. (Sat'n. Temp. −93.8° F.)			Abs. Pressure 3.5 lb./in.² Gage Pressure 22.80 in. Vac. (Sat'n. Temp. −89.4° F.)		
t	*v*	*h*	*s*	*v*	*h*	*s*	*v*	*h*	*s*
(*at sat'n.*)	(*17.641*)	(*93.43*)	(*0.26210*)	(*14.889*)	(*94.04*)	(*0.25966*)	(*12.903*)	(*94.57*)	(*0.25759*)
− 90	18.076	94.53	.26504	15.046	94.51	0.26086			
− 80	18.572	95.80	.26841	15.460	95.78	.26423	13.236	95.76	0.26069
− 70	19.068	97.08	.27173	15.873	97.06	.26755	13.591	97.04	.26401
− 60	19.563	98.38	.27500	16.287	98.36	.27082	13.946	98.33	.26728
− 50	20.059	99.69	.27823	16.700	99.67	0.27405	14.301	99.64	0.27051
− 40	20.554	101.01	.28143	17.113	100.99	.27725	14.656	100.97	.27371
− 30	21.049	102.35	.28459	17.527	102.33	.28041	15.010	102.31	.27687
− 20	21.544	103.70	.28771	17.939	103.68	.28353	15.365	103.66	.28000
− 10	22.038	105.07	.29080	18.352	105.05	.28662	15.719	105.03	.28309
0	22.533	106.45	.29385	18.764	106.43	0.28967	16.073	106.42	0.28614
10	23.027	107.85	.29686	19.177	107.83	.29269	16.427	107.82	.28916
20	23.522	109.26	.29984	19.589	109.24	.29567	16.780	109.23	.29214
30	24.016	110.69	.30279	20.001	110.67	.29862	17.134	110.65	.29509
40	24.510	112.13	.30570	20.412	112.11	.30153	17.487	112.09	.29800
50	25.004	113.59	.30858	20.825	113.57	0.30441	17.840	113.55	0.30088
60	25.498	115.06	.31143	21.237	115.04	.30726	18.194	115.02	.30373
70	25.992	116.54	.31426	21.649	116.53	.31009	18.547	116.51	.30656
80	26.486	118.04	.31707	22.061	118.03	.31290	18.900	118.01	.30937
90	26.979	119.56	.31986	22.472	119.54	.31569	19.254	119.53	.31216
100	27.473	121.09	0.32262	22.884	121.07	0.31845	19.607	121.06	0.31493
110	27.967	122.63	.32536	23.296	122.62	.32119	19.960	122.60	.31767
120	28.461	124.19	.32808	23.708	124.18	.32391	20.313	124.16	.32039
130	28.954	125.77	.33077	24.120	125.75	.32661	20.666	125.74	.32308
140	29.448	127.36	.33344	24.531	127.34	.32928	21.019	127.33	.32575
150	29.941	128.96	0.33609	24.943	128.95	0.33193	21.372	128.93	0.32840
160	30.435	130.58	.33872	25.354	130.56	.33456	21.725	130.55	.33103
170	30.928	132.21	.34133	25.765	132.20	.33717	22.078	132.19	.33365
180	31.421	133.86	.34393	26.176	133.85	.33977	22.430	133.83	.33625
190	31.914	135.52	.34651	26.588	135.51	.34235	22.783	135.50	.33883
200	32.408	137.20	0.34907	26.999	137.19	0.34491	23.136	137.17	0.34139
210	32.901	138.89	.35161	27.410	138.88	.34745	23.488	138.87	.34393
220	.....	......	....			.	23.841	140.58	.34645

TABLE 2A-17. PROPERTIES OF SUPERHEATED VAPOR, FREON 22 (*Continued*)

Temp., °F.	Abs. Pressure 4.0 lb./in.² Gage Pressure 21.78 in. Vac. (Sat'n. Temp. −85.4° F.)			Abs. Pressure 4.5 lb./in.² Gage Pressure 20.76 in. Vac. (Sat'n. Temp. −82.0° F.)			Abs. Pressure 5.0 lb./in.² Gage Pressure 19.74 in. Vac. (Sat'n. Temp. −78.7° F.)		
t	*v*	*h*	*s*	*v*	*h*	*s*	*v*	*h*	*s*
(at sat'n.)	*(11.401)*	*(95.05)*	*(0.25583)*	*(10.217)*	*(95.46)*	*(0.25432)*	*(9.2662)*	*(95.85)*	*(0.25294)*
− 80	11.569	95.74	0.25762	10.272	95.71	0.25491	.....	..	.....
− 70	11.880	97.02	.26094	10.549	96.99	.25823	9.4827	96.97	0.25578
− 60	12.191	98.31	.26421	10.825	98.29	.26150	9.7333	98.27	.25906
− 50	12.502	99.62	0.26744	11.102	99.60	0.26473	9.9828	99.58	0.26230
− 40	12.812	100.95	.27064	11.379	100.93	.26793	10.232	100.91	.26550
− 30	13.123	102.29	.27380	11.655	102.27	.27109	10.481	102.25	.26867
− 20	13.434	103.64	.27693	11.932	103.62	.27422	10.729	103.60	.27180
− 10	13.744	105.01	.28002	12.208	105.00	.27731	10.978	104.98	.27489
0	14.054	106.40	0.28308	12.483	106.38	0.28037	11.226	106.36	0.27795
10	14.364	107.80	.28610	12.759	107.78	.28339	11.475	107.76	.28097
20	14.674	109.21	.28909	13.035	109.19	.28638	11.723	109.18	.28396
30	14.983	110.64	.29204	13.310	110.62	.28933	11.972	110.61	.28691
40	15.293	112.08	.29495	13.586	112.07	.29224	12.220	112.05	.28983
50	15.602	113.54	0.29783	13.861	113.52	0.29512	12.468	113.51	0.29271
60	15.912	115.01	.30068	14.136	115.00	.29797	12.715	114.98	.29556
70	16.221	116.50	.30351	14.411	116.48	.30080	12.963	116.47	.29839
80	16.530	118.00	.30632	14.686	117.99	.30361	13.211	117.97	.30120
90	16.839	119.52	.30911	14.961	119.50	.30640	13.460	119.49	.30399
100	17.149	121.05	0.31187	15.237	121.03	0.30917	13.707	121.02	0.30676
110	17.458	122.59	.31461	15.512	122.58	.31191	13.955	122.57	.30950
120	17.767	124.15	.31733	15.787	124.14	.31463	14.202	124.13	.31222
130	18.076	125.72	.32003	16.062	125.71	.31733	14.450	125.70	.31492
140	18.385	127.31	.32270	16.337	127.30	.32000	14.697	127.29	.31759
150	18.694	128.92	0.32535	16.611	128.91	0.32265	14.945	128.90	0.32024
160	19.003	130.54	.32798	16.886	130.53	.32529	15.192	130.51	.32288
170	19.311	132.17	.33060	17.161	132.16	.32791	15.440	132.15	.32550
180	19.621	133.82	.33320	17.435	133.81	.33051	15.687	133.80	.32810
190	19.929	135.48	.33578	17.710	135.47	.33309	15.934	135.46	.33068
200	20.238	137.16	0.33834	17.984	137.15	0.33565	16.181	137.14	0.33324
210	20.547	138.86	.34088	18.259	138.84	.33819	16.429	138.83	.33578
220	20.855	140.56	.34340	18.533	140.55	.34071	16.676	140.54	.33830
230	.....	..	....	....	..	....	16.923	142.26	.34081

TABLE 2A-17. PROPERTIES OF SUPERHEATED VAPOR, FREON 22 (*Continued*)

Temp., °F.	Abs. Pressure 6 lb./in.² Gage Pressure 17.71 in. Vac. (Sat'n. Temp. −73.0° F.)			Abs. Pressure 7 lb./in.² Gage Pressure 15.67 in. Vac. (Sat'n. Temp. −68.0° F.)			Abs. Pressure 8 lb./in.² Gage Pressure 13.64 in. Vac. (Sat'n. Temp. −63.5° F.)		
t	*v*	*h*	*s*	*v*	*h*	*s*	*v*	*h*	*s*
(*at sat'n.*)	(*7.8232*)	(*96.54*)	(*0.25060*)	(*6.7806*)	(*97.14*)	(*0.24868*)	(*5.9909*)	(*97.68*)	(*0.24705*)
− 70	7.8855	96.93	0.25157	....	....	....	....	....	....
− 60	8.0947	98.22	.25485	6.9240	98.18	0.25127	6.0459	98.14	0.24817
− 50	8.3026	99.54	0.25809	7.1030	99.50	0.25452	6.2036	99.46	0.25142
− 40	8.5112	100.87	.26129	7.2819	100.82	.25773	6.3613	100.78	.25463
− 30	8.7192	102.21	.26446	7.4610	102.17	.26090	6.5174	102.12	.25781
− 20	8.9270	103.56	.26759	7.6396	103.53	.26404	6.6734	103.49	.26095
− 10	9.1346	104.94	.27069	7.8178	104.90	.26714	6.8300	104.86	.26405
0	9.3419	106.33	0.27375	7.9959	106.29	0.27020	6.9864	106.25	0.26711
10	9.5494	107.73	.27677	8.1740	107.69	.27322	7.1426	107.65	.27013
20	9.7567	109.14	.27976	8.3521	109.11	.27621	7.2987	109.07	.27312
30	9.9641	110.57	.28271	8.5304	110.54	.27916	7.4545	110.50	.27608
40	10.171	112.02	.28563	8.7081	111.98	.28208	7.6106	111.95	.27900
50	10.378	113.48	0.28852	8.8860	113.44	0.28497	7.7668	113.41	0.28189
60	10.585	114.95	.29138	9.0637	114.92	.28783	7.9223	114.89	.28475
70	10.792	116.44	.29421	9.2413	116.41	.29067	8.0780	116.38	.28759
80	10.999	117.94	.29702	9.4189	117.91	.29348	8.2338	117.88	.29041
90	11.206	119.46	.29981	9.5966	119.43	.29627	8.3893	119.40	.29320
100	11.413	120.99	0.30258	9.7743	120.96	0.29904	8.5449	120.93	0.29597
110	11.620	122.54	.30532	9.9515	122.51	.30178	8.7002	122.48	.29871
120	11.826	124.10	.30804	10.129	124.07	.30450	8.8556	124.04	.30143
130	12.033	125.68	.31074	10.306	125.65	.30720	9.0110	125.62	.30413
140	12.239	127.27	.31342	10.483	127.24	.30988	9.1661	127.21	.30681
150	12.446	128.87	0.31607	10.660	128.84	0.31253	9.3213	128.82	0.30946
160	12.652	130.49	.31870	10.837	130.47	.31516	9.4766	130.44	.31209
170	12.859	132.13	.32132	11.014	132.10	.31778	9.6319	132.08	.31471
180	13.065	133.77	.32392	11.192	133.75	.32038	9.7869	133.73	.31731
190	13.271	135.43	.32650	11.369	135.42	.32296	9.9419	135.39	.31990
200	13.477	137.11	0.32906	11.545	137.10	0.32553	10.097	137.07	0.32247
210	13.683	138.81	.33160	11.722	138.79	.32808	10.252	138.77	.32502
220	13.889	140.52	.33412	11.899	140.49	.33061	10.407	140.47	.32756
230	14.096	142.24	.33663	12.076	142.22	.33312	10.562	142.20	.33008
240	....	......	....	12.253	143.96	.33562	10.717	143.93	.33258

TABLE 2A-17. PROPERTIES OF SUPERHEATED VAPOR, FREON 22 (*Continued*)

Temp., °F.	Abs. Pressure 9 lb./in.^{2} Gage Pressure 11.60 in. Vac. (Sat'n. Temp. −59.5° F.)			Abs. Pressure 10 lb./in.^{2} Gage Pressure 9.57 in. Vac. (Sat'n. Temp. −55.8° F.)			Abs. Pressure 11 lb./in.^{2} Gage Pressure 7.53 in. Vac. (Sat'n. Temp. −52.4° F.)		
t	*v*	*h*	*s*	*v*	*h*	*s*	*v*	*h*	*s*
(*at sat'n.*)	(*5.3703*)	(*93.16*)	(*0.24562*)	(*4.8701*)	(*98.60*)	(*0.24435*)	(*4.4576*)	(*99.01*)	(*0.24324*)
−50	5.5032	99.41	0.24868	4.9432	99.37	0.24622	4.4850	99.33	0.24399
−40	5.6431	100.74	.25190	5.0693	100.70	.24944	4.5999	100.66	.24721
−30	5.7827	102.08	.25508	5.1952	102.04	.25262	4.7146	102.00	.25039
−20	5.9226	103.45	.25822	5.3214	103.41	.25576	4.8296	103.37	.25354
−10	6.0621	104.83	.26132	5.4473	104.79	.25886	4.9443	104.75	.25665
0	6.2012	106.21	0.26438	5.5728	106.18	0.26193	5.0587	106.14	0.25972
10	6.3405	107.62	.26741	5.6986	107.58	.26497	5.1734	107.55	.26276
20	6.4794	109.04	.27040	5.8240	109.00	.26797	5.2877	108.97	.26576
30	6.6184	110.47	.27336	5.9495	110.42	.27093	5.4017	110.40	.26872
40	6.7569	111.92	.27628	6.0746	111.88	.27385	5.5158	111.85	.27164
50	6.8963	113.38	0.27917	6.1999	113.34	0.27674	5.6296	113.31	0.27453
60	7.0351	114.85	.28203	6.3247	114.82	.27960	5.7434	114.79	.27739
70	7.1733	116.34	.28487	6.4496	116.31	.28244	5.8574	116.28	.28023
80	7.3117	117.85	.28769	6.5746	117.82	.28526	5.9710	117.79	.28305
90	7.4501	119.37	.29048	6.6998	119.34	.28805	6.0847	119.31	.28585
100	7.5887	120.90	0.29325	6.8244	120.87	0.29082	6.1985	120.84	0.28862
110	7.7270	122.45	.29600	6.9491	122.42	.29357	6.3117	122.39	.29137
120	7.8654	124.02	.29872	7.0732	123.99	.29629	6.4251	123.96	.29410
130	8.0035	125.59	.30142	7.1981	125.57	.29899	6.5385	125.54	.29680
140	8.1416	127.19	.30410	7.3224	127.16	.30167	6.6521	127.13	.29948
150	8.2799	128.79	0.30676	7.4467	128.76	0.30433	6.7657	128.74	0.30214
160	8.4182	130.41	.30940	7.5711	130.39	.30697	6.8787	130.36	.30478
170	8.5562	132.05	.31202	7.6956	132.03	.30959	6.9918	132.00	.30740
180	8.6943	133.70	.31462	7.8202	133.68	.31219	7.1050	133.65	.31000
190	8.8320	135.37	.31720	7.9448	135.34	.31477	7.2182	135.32	.31258
200	8.9697	137.05	0.31976	8.0687	137.02	0.31734	7.3308	137.00	0.31515
210	9.1075	138.74	.32231	8.1927	138.72	.31989	7.4442	138.70	.31770
220	9.2454	140.45	.32485	8.3167	140.43	.32243	7.5568	140.41	.32024
230	9.3833	142.17	.32737	8.4407	142.15	.32495	7.6703	142.13	.32276
240	9.5212	143.91	.32988	8.5648	143.89	.32746	7.7831	143.87	.32527
250	9.6593	145.67	0.33237	8.6890	145.65	0.32995	7.8959	145.62	0.32776

TABLE 2A–17. PROPERTIES OF SUPERHEATED VAPOR, FREON 22 (*Continued*)

Temp., °F.	Abs. Pressure 12 lb./in.^{2} Gage Pressure 5.50 in. Vac. (Sat'n. Temp. −49.2° F.)			Abs. Pressure 14 lb./in.^{2} Gage Pressure 1.42 in. Vac. (Sat'n. Temp. −43.5° F.)			Abs. Pressure 16 lb./in.^{2} Gage Pressure 1.3 lb./in.^{2} (Sat'n. Temp. −38.3° F.)		
t	*v*	*h*	*s*	*v*	*h*	*s*	*v*	*h*	*s*
(*at sat'n.*)	(*4.1118*)	(*99.39*)	(*0.24221*)	(*3.5624*)	(*100.07*)	(*0.20444*)	(*3.1464*)	(*100.68*)	(*0.23895*)
− 40	4.2091	100.62	0.24517	3.5945	100.53	0.24154			. . .
− 30	4.3145	101.96	.24836	3.6852	101.88	.24473	3.2132	101.80	0.24158
− 20	4.4201	103.33	.25151	3.7761	103.25	.24788	3 2031	103.18	.24474
− 10	4.5251	104.71	.25462	3.8665	104.64	.25100	3.3733	104.56	.24786
0	4.6303	106.10	0.25769	3 9572	106 03	0.25408	3.4524	105.95	0.25094
10	4.7353	107.51	.26073	4.0476	107.44	.25712	3.5316	107.36	.25398
20	4.8404	108.93	.26373	4.1379	108.86	.26012	3.6111	108.79	.25699
30	4.9452	110.37	.26669	4.2279	110.30	.26309	3.6904	110.23	.25996
40	5.0502	111.81	.26962	4.3181	111.75	.26602	3.7694	111.68	.26290
50	5.1548	113.28	0.27251	4.4084	113.21	0.26892	3.8483	113.15	0.26580
60	5.2596	114.76	.27537	4.4985	114.69	.27179	3.9277	114.63	.26867
70	5.3640	116.25	.27821	4.5882	116.19	.27463	4.0064	116.13	.27152
80	5.4680	117.76	.28103	4.6781	117.70	.27745	4.0853	117.64	.27435
90	5.5727	119.28	.28383	4.7676	119.22	.28025	4.1638	119.16	.27715
100	5.6769	120.82	0.28661	4.8572	120.76	0.28303	4.2425	120.70	0.27993
110	5.7812	122.37	.28936	4.9470	122.31	.28578	4.3209	122.25	.28268
120	5.8850	123.93	.29209	5.0363	123.88	.28851	4 3994	133.82	.28541
130	5.9889	125.51	.29479	5.1257	125.46	.29122	4.4779	125.40	.28812
140	6.0929	127.10	.29747	5.2147	127.05	.29390	4.5566	127.00	.29081
150	6.1970	128.71	0.30013	5.3043	128.66	0.29656	4.6349	128.61	0.29347
160	6.3011	130.34	.30277	5.3935	130.29	.29920	4.7132	130.23	.29611
170	6.4054	131.98	.30539	5.4832	131.93	.30182	4.7917	131.88	.29874
180	6.5090	133.63	.30799	5 5725	133.58	.30443	4.8697	133 53	.30135
190	6.6128	135.29	.31058	5.6613	135.25	.30702	4.9478	135.20	.30394
200	6.7166	136.98	0.31315	5.7502	136.93	0.30959	5.0259	136.88	0.30651
210	6.8204	138.67	.31570	5.8397	138.63	.31214	5.1042	138.58	.30906
220	6.9237	140.38	.31824	5.9287	140.34	.31468	5.1819	140.29	.31160
230	7.0276	142.11	.32076	6.0177	142.07	.31720	5.2603	142.02	.31412
240	7.1310	143.85	.32327	6.1068	143.81	.31971	5.3381	143.76	.31663
250	7.2343	145.60	0.32576	6.1959	145.56	0.32221	5.4161	145.52	0.31913
260	7.3377	147.37	.32824	6.2845	147.33	.32469	5.4940	147.29	.32162
270	......	.....	. .	...	..	..	5.5720	149.07	.32409

TABLE 2A–17. PROPERTIES OF SUPERHEATED VAPOR, FREON 22 (*Continued*)

Temp., °F.	Abs. Pressure 18 lb./in.^{2} Gage Pressure 3.3 lb./in.^{2} (Sat'n. Temp. −33.7° F.)			Abs. Pressure 20 lb./in.^{2} Gage Pressure 5.3 lb./in.^{2} (Sat'n. Temp. −29.4° F.)			Abs. Pressure 25 lb./in.^{2} Gage Pressure 10.3 lb./in.^{2} (Sat'n. Temp. −20.0° F.)		
t	*v*	*h*	*s*	*v*	*h*	*s*	*v*	*h*	*s*
(*at sat'n*)	(*2.8192*)	(*101.22*)	(*0.23763*)	(*2.5558*)	(*101.72*)	(*0.23647*)	(*2.0748*)	(*102.81*)	(*0.23406*)
−30	2.8457	101.72	0.23879				.	... .	....
−20	2.9170	103.10	.24196	2.6162	103.02	0.23944		.	....
−10	2.9880	104.48	.24508	2.6806	104.40	.24257	2.1270	104.21	0.23723
0	3.0592	105.88	0.24816	2.7450	105.80	0.24566	2.1791	105.61	0.24033
10	3.1303	107.29	.25120	2.8091	107.22	.24871	2.2310	107.03	.24339
20	3.2014	108.72	.25421	2.8734	108.65	.25173	2.2829	108.47	.24642
30	3.2720	110.16	.25719	2.9373	110.09	.25471	2.3346	109.91	.24941
40	3.3427	111.61	.26013	3.0011	111.54	.25765	2.3860	111.37	.25236
50	3.4133	113.08	0.26304	3.0648	113.02	0.26056	2.4373	112.85	0.25528
60	3.4837	114.57	.26592	3.1283	114.50	.26344	2.4887	114.34	.25817
70	3.5539	116.06	.26877	3.1919	116.00	.26629	2.5401	115.84	.26103
80	3.6242	117.58	.27160	3.2554	117.51	.26912	2.5913	117.36	.26387
90	3.6943	119.10	.27440	3.3186	119.04	.27193	2.6425	118.89	.26668
100	3.7644	120.64	0.27718	3.38[illegible]	120.58	0.27472	2.6934	120.44	0.26947
110	3.8343	122.20	.27993	3.4452	122.14	.27748	2.7443	122.00	.27223
120	3.9044	123.76	.28266	3.5084	123.71	.28021	2.7952	123.57	.27497
130	3.9745	125.35	.28537	3.5714	125.29	.28292	2.8459	125.16	.27769
140	4.0443	126.94	.28806	3.6345	126.89	.28561	2.8967	126.76	.28039
150	4.1142	128.56	0.29073	3.6976	128.51	0.28828	2.9474	128.38	0.28306
160	4.1837	130.18	.29338	3.7605	130.13	.29093	2.9981	130.01	.28571
170	4.2538	131.83	.29601	3.8235	131.78	.29356	3.0489	131.65	.28834
180	4.3235	133.48	.29862	3.8861	133.43	.29617	3.0994	133.31	.29096
190	4.3932	135.15	.30121	3.9488	135.10	.29876	3.1500	134.98	.29356
200	4.4626	136.84	0.30378	4.0116	136.79	0.30133	3.2004	136.67	0.29614
210	4.5321	138.54	.30634	4.0744	138.49	.30389	3.2509	138.38	.29870
220	4.6016	140.25	.30888	4.1373	140.21	.30643	3.3014	140.09	.30124
230	4.6711	141.98	.31140	4.1999	141.93	.30896	3.3516	141.82	.30377
240	4.7403	143.72	.31391	4.2625	143.68	.31147	3.4019	143.57	.30629
250	4.8099	145.48	0.31641	4.3251	145.44	0.31397	3.4522	145.33	0.30879
260	4.8797	147.25	.31890	4.3878	147.21	.31646	3.5026	147.10	.31128
270	4.9490	149.04	.32138	4.4501	149.00	.31894	3.5527	148.90	.31376
280	....	....	.	4.5124	150.80	.32141	3.6028	150.70	.31622
290	... ..	. ...	....	.	.. .	....	3.6530	152.52	.31867

TABLE 2A-17. PROPERTIES OF SUPERHEATED VAPOR, FREON-22 (*Continued*)

Temp., °F.	Abs. Pressure 30 lb./in.^{2} Gage Pressure 15.3 lb./in.^{2} (Sat'n. Temp. −12.0° F.)			Abs. Pressure 35 lb./in.^{2} Gage Pressure 20.3 lb./in.^{2} (Sat'n. Temp. −4.9° F.)			Abs. Pressure 40 lb./in.^{2} Gage Pressure 25.3 lb./in.^{2} (Sat'n. Temp. 1.3° F.)		
t	*v*	*h*	*s*	*v*	*h*	*s*	*v*	*h*	*s*
(*at sat'n.*)	(*1.7438*)	(*103.71*)	(*0.23217*)	(*1.5130*)	(*104.51*)	(*0.23060*)	(*1.3335*)	(*105.18*)	(*0.22925*)
− 10	1.7576	104.00	0.23279					.. ...	.... . .
0	1.8015	105.41	0.23591	1.5315	105.21	0.23213		.. ..	....
10	1.8453	106 84	.23899	1.5696	106.64	.23522	1.3628	106.43	0.23192
20	1.8891	108.28	.24203	1.6075	108.09	.23827	1.3963	107.89	.23498
30	1.9326	109.73	.24503	1.6452	109.55	.24128	1.4296	109.36	.23800
40	1.9758	111.20	.24799	1.6829	111.02	.24426	1.4628	110.84	.24099
50	2.0193	112.68	0.25092	1.7204	112.51	0.24720	1.4961	112.33	0.24394
60	2.0625	114.17	.25382	1.7578	114.01	.25011	1.5293	113.83	.24686
70	2.1057	115.68	.25669	1.7953	115 52	.25299	1.5621	115.35	.24975
80	2.1488	117.20	.25954	1.8324	117.04	.25585	1.5950	116.88	.25261
90	2.1916	118.74	.26236	1.8694	118.58	.25868	1.6277	118.42	.25545
100	2.2345	120.29	0.26516	1.9064	120.14	0.26148	1.6603	119.98	0.25826
110	2.2771	121 85	.26793	1.9433	121.70	.26426	1.6929	121.55	.26104
120	2.3198	123 43	.27067	1.9803	123 28	.26701	1.7257	123.14	.26380
130	2.3623	125 02	.27339	2 0170	124.88	.26974	1.7580	124 74	.26654
140	2.4050	126.63	.27609	2.0538	126.49	.27244	1.7902	126.35	.26925
150	2.4475	128.24	0.27877	2.0905	128.11	0.27512	1.8226	127.98	0.27194
160	2.4901	129.88	.28143	2 1273	129.75	.27778	1.8550	129.62	.27461
170	2.5325	131.53	.28407	2.1637	131.40	.28042	1.8871	131.27	.27726
180	2.5750	133 19	.28669	2 2002	133 06	.28304	1.9192	132.94	.27989
190	2.6173	134.86	.28929	2.2368	134.74	.28565	1.9513	134.62	.28250
200	2.6594	136.56	0.29187	2.2732	136.44	0.28824	1.9834	136.32	0.28509
210	2.7019	138 26	.29444	2 3095	138.14	.29081	2.0155	138.03	.28766
220	2.7441	139 98	.29699	2 3459	139 85	.29337	2.0474	139.75	.29022
230	2.7864	141.71	.29952	2.3822	141.60	.29591	2.0793	141.49	.29276
240	2.8285	143.46	.30204	2.4187	143.35	.29843	2.1114	143.24	.29528
250	2.8706	145.22	0.30454	2.4550	145.12	0.30093	2 1432	145.01	0.29779
260	2.9125	147 00	.30703	2.4910	146 90	.30342	2.1749	146.79	.30028
270	2 9547	148.79	.30950	2 5271	148.69	.30589	2.2067	148.59	.30276
280	2.9967	150.60	.31196	2 5633	150.50	.30835	2.2385	150.40	.30522
290	3.0387	152.42	.31441	2.5995	152.32	.31080	2.2703	152.22	.30767
300	......	. .	.	2.6357	154.16	0.31324	2.3019	154.06	0.31011
310	.. .		. .			. ..	2.3336	155.91	.31254

TABLE 2A–17. PROPERTIES OF SUPERHEATED VAPOR, FREON ·22 (*Continued*)

Temp., °F.	Abs. Pressure 45 lb./in.^{2} Gage Pressure 30.3 lb./in.^{2} (Sat'n. Temp. 7.1° F.)			Abs. Pressure 50 lb./in.^{2} Gage Pressure 35.3 lb./in.^{2} (Sat'n. Temp. 12 4° F.)			Abs. Pressure 55 lb./in.^{2} Gage Pressure 40.3 lb./in.^{2} (Sat'n Temp. 17.2° F.)		
t	*v*	*h*	*s*	*v*	*h*	*s*	*v*	*h*	*s*
(at sat'n.)	*(1.1934)*	*(105.61)*	*(0.22751)*	*(1.0794)*	*(106.16)*	*(0.22647)*	*(.98546)*	*(106.66)*	*(0.22552)*
10	1.2018	106 02	0.22838	. ..	. .	.	.	. .	.. .
20	1.2321	107.48	.23146	1.1002	107.28	0.22880	.99219	107.07	0.22637
30	1.2619	108.96	.23450	1.1275	108.76	.23185	1.0176	108.56	.22943
40	1.2917	110.45	.23750	1.1547	110.26	.23486	1.0425	110.07	.23245
50	1.3215	111.95	0.24046	1.1819	111.76	0.23783	1.0675	111.58	0.23543
60	1.3512	113.44	.24339	1.2087	113.27	.24077	1.0921	113.08	.23838
70	1.3806	114.96	.24629	1.2357	114 79	.24368	1 1168	114.62	.24130
80	1.4102	116.51	.24916	1.2624	116 34	.24656	1.1414	116.17	.24419
90	1.4395	118.06	.25200	1.2891	117.90	.24941	1.1659	117.73	.24705
100	1.4689	119.61	0.25482	1.3157	119.46	0.25224	1.1902	119.30	0.24989
110	1.4980	121.18	.25761	1.3422	121.03	.25504	1.2146	120 88	.25270
120	1.5271	122.77	.26037	1.3685	122.63	.25781	1.2386	122.48	.25548
130	1.5562	124.37	.26311	1.3950	124 23	.26056	1 2627	124.09	.25823
140	1.5853	125.99	.26583	1.4213	125.85	.26329	1.2870	125.71	.26096
150	1.6143	127.62	0.26853	1.4476	127 48	0.26599	1.3110	127.34	0.26367
160	1.6431	129.27	.27121	1.4737	129.13	.26867	1.3349	129.00	.26636
170	1.6721	130.92	.27387	1.4999	130.79	.27133	1 3590	130.66	.26903
180	1.7008	132.59	.27650	1.5258	132 47	.27397	1.3827	132.34	.27167
190	1.7296	134.28	.27911	1.5519	134.15	.27658	1.4065	134.03	.27429
200	1.7581	135.98	0.28170	1.5777	135.85	0.27918	1.4301	135.73	0.27689
210	1.7866	137.69	.28428	1.6036	137.57	.28176	1.4539	137.45	.27948
220	1.8151	139 42	.28685	1.6295	139.30	.28433	1.4774	139.18	.28205
230	1.8438	141.15	.28940	1.6554	141 04	.28688	1.5011	140.92	.28460
240	1.8722	142.91	.29193	1.6810	142.80	.28941	1.5246	142.68	.28713
250	1.9023	144.67	0.29444	1.7069	144.56	0.29192	1.5481	144.46	0.28964
260	1.9306	146.46	.29693	1.7324	146.35	.29442	1.5716	146.24	.29214
270	1.9590	148.26	.29941	1.7581	148.15	.29691	1.5950	148.05	.29463
280	1.9874	150.08	.30188	1.7837	149.98	.29938	1.6184	149.87	.29710
290	2.0156	151.91	.30433	1.8095	151.81	.30183	1.6417	151.71	.29956
300	2.0439	153.74	0.30677	1.8349	153.65	0.30427	1.6651	153.55	0.30201
310	2.0721	155.60	.30919	1.8605	155.50	.30670	1.6883	155.41	.30445
320	.. ...		.	1.8859	157.38	.30912	1.7116	157.28	.30687

TABLE 2A–17. PROPERTIES OF SUPERHEATED VAPOR, FREON 22 (*Continued*)

Temp., °F.	Abs. Pressure 60 lb./in.^{2} Gage Pressure 45.3 lb./in.^{2} (Sat'n. Temp. 21.8° F.)			Abs. Pressure 65 lb./in.^{2} Gage Pressure 50.3 lb./in.^{2} (Sat'n. Temp. 26.0° F.)			Abs. Pressure 70 lb./in.^{2} Gage Pressure 55.3 lb./in.^{2} (Sat'n. Temp. 30.0° F.)		
t	*v*	*h*	*s*	*v*	*h*	*s*	*v*	*h*	*s*
(*at sat'n.*)	(*0.90642*)	(*107.14*)	(*0.22468*)	(*0.83899*)	(*107.56*)	(*0.22386*)	(*0.78094*)	(*107.95*)	(*0.22314*)
30	0.92548	108.36	0.22717	0.84803	108.16	0.22510			
40	.94911	109.87	.23021	.86997	109.68	.22815	0.80229	109.47	0.22620
50	0.97207	111.39	0.23321	0.89165	111.19	0.23116	0.82241	110.99	0.22923
60	.99503	112.90	.23618	.91295	112.71	.23414	.84242	112.51	.23222
70	1.0180	114.44	.23912	.93425	114.26	.23708	.86245	114.07	.23517
80	1.0406	116.00	.24202	.95572	115.82	.23999	.88225	115.64	.23809
90	1.0634	117.57	.24489	.97626	117.40	.24287	.90187	117.23	.24098
100	1.0858	119.15	0.24773	0.99730	118.98	0.24572	0.92155	118.82	0.24384
110	1.1082	120.72	.25054	1.0183	120.57	.24854	.94111	120.41	.24667
120	1.1305	122.33	.25332	1.0390	122.18	.25133	.96052	122.03	.24947
130	1.1529	123.94	.25608	1.0598	123.80	.25410	.97996	123.65	.25225
140	1.1751	125.57	.25882	1.0804	125.43	.25684	.99913	125.28	.25500
150	1.1974	127.21	0.26154	1.1010	127.07	0.25956	1.0187	126.92	0.25773
160	1.2193	128.86	.26423	1.1217	128.73	.26226	1.0379	128.59	.26043
170	1.2415	130.53	.26690	1.1421	130.40	.26494	1.0569	130.27	.26311
180	1.2634	132.21	.26955	1.1627	132.08	.26759	1.0762	131.95	.26577
190	1.2853	133.90	.27218	1.1829	133.78	.27022	1.0951	133.65	.26841
200	1.3071	135.61	0.27478	1.2031	135.48	0.27283	1.1139	135.36	0.27102
210	1.3290	137.33	.27737	1.2234	137.21	.27542	1.1330	137.09	.27361
220	1.3509	139.06	.27994	1.2437	138.95	.27800	1.1519	138.83	.27619
230	1.3726	140.81	.28250	1.2639	140.69	.28056	1.1707	140.58	.27876
240	1.3943	142.57	.28504	1.2841	142.46	.28310	1.1894	142.34	.28131
250	1.4159	144.35	0.28756	1.3041	144.23	0.28563	1.2082	144.12	0.28384
260	1.4375	146.13	.29006	1.3240	146.03	.28814	1.2268	145.92	.28635
270	1.4591	147.94	.29255	1.3441	147.84	.29064	1.2456	147.73	.28885
280	1.4806	149.77	.29503	1.3641	149.67	.29312	1.2642	149.56	.29133
290	1.5021	151.61	.29749	1.3840	151.51	.29558	1.2829	151.40	.29380
300	1.5235	153.45	0.29994	1.4038	153.35	0.29083	1.3013	153.25	0.29625
310	1.5451	155.31	.30238	1.4237	155.21	.30047	1.3198	155.11	.29869
320	1.5665	157.19	.30481	1.4436	157.09	.30290	1.3384	157.00	.30112
330	1.5879	159.07	.30723	1.4634	158.98	.30532	1.3569	158.89	.30354
340	....			.		.	1.3753	160.79	.30595

Table 2a–17. Properties of Superheated Vapor, Freon 22 (*Continued*)

Temp., °F.	Abs. Pressure 75 lb./in.^{2} Gage Pressure 60.3 lb./in.^{2} (Sat'n. Temp. 33.8° F.)			Abs. Pressure 80 lb./in.^{2} Gage Pressure 65.3 lb./in.^{2} (Sat'n. Temp. 37.4° F.)			Abs. Pressure 90 lb./in.^{2} Gage Pressure 75.3 lb./in.^{2} (Sat'n. Temp. 44.2° F.)		
t	*v*	*h*	*s*	*v*	*h*	*s*	*v*	*h*	*s*
(*at sat'n.*)	(*0.73041*)	(*108.32*)	(*0.22246*)	(*0.68595*)	(*108.67*)	(*0.22182*)	(*0.61094*)	(*109.23*)	(*0.22062*)
40	0.74209	109.27	0.22434	0.69040	109.06	0.22261	.	. .	. . . . .
50	0.76150	110.80	0.22739	0.70874	110.60	0.22567	0.62073	110.19	0.22246
60	.78071	112.32	.23040	.72692	112.12	.22869	.63717	111.72	.22550
70	.79954	113.89	.23337	.74457	113.70	.23167	.65353	113.31	.22850
80	.81818	115.47	.23630	.76253	115.28	.23461	.66974	114.92	.23147
90	.83675	117.06	.23920	.78011	116.89	.23752	.68577	116.53	.23441
100	0.85531	118.66	0.24207	0.79783	118.49	0.24040	0.70177	118.15	0.23731
110	.87385	120.25	.24491	.81512	120.09	.24325	.71754	119.76	.24018
120	.89228	121.87	.24772	.83268	121.71	.24607	.73338	121.39	.24302
130	.91066	123.50	.25050	.84999	123.35	.24886	.74894	123.03	.24583
140	.92891	125.14	.25326	.86725	124.99	.25163	.76449	124.69	.24861
150	0.94700	126.79	0.25600	0.88437	126.64	0.25437	0.78000	126.35	0.25137
160	.96500	128.45	.25871	.90135	128.31	.25708	.79541	128.03	.25410
170	.98309	130.13	.26140	.91842	129.99	.25977	.81083	129.72	.25680
180	1.0012	131.82	.26406	.93558	131.69	.26244	.82620	131.42	.25948
190	1.0188	133.52	.26670	.95238	133.39	.26509	.84111	133.14	.26214
200	1.0366	135.24	0.26932	0.96889	135.11	0.26772	0.85608	134.86	0.26478
210	1.0544	136.97	.27192	.98565	136.84	.27033	.87113	136.60	.26740
220	1.0722	138.71	.27451	1.0025	138.59	.27292	.88625	138.35	.27000
230	1.0898	140.46	.27708	1.0192	140.34	.27549	.90127	140.11	.27258
240	1.1075	142.23	.27963	1.0358	142.12	.27805	.91626	141.88	.27514
250	1.1250	144.01	0.28216	1.0524	143.90	0.28059	0.93115	143.67	0.27769
260	1.1426	145.81	.28468	1.0690	145.70	.28311	.94599	145.47	.28022
270	1.1601	147.62	.28718	1.0854	147.52	.28561	.96080	147.30	.28273
280	1.1776	149.46	.28966	1.1019	149.35	.28809	.97557	149.14	.28522
290	1.1949	151.30	.29213	1.1183	151.20	.29056	.99020	150.99	.28770
300	1.2122	153.15	0.29459	1.1343	153.05	0.29302	1.0048	152.85	0.29016
310	1.2296	155.02	.29704	1.1507	154.92	.29547	1.0194	154.72	.29261
320	1.2481	156.90	.29947	1.1671	156.80	.29790	1.0341	156.61	.29505
330	1.2655	158.79	.30189	1.1834	158.70	.30032	1.0487	158.51	.29747
340	1.2829	160.70	.30430	1.1996	160.60	.30273	1.0633	160.42	.29988
350	. . . . .	. . .	.	. . .	.	. . . . . .	1.0779	162.34	0.30228

TABLE 2A-17. PROPERTIES OF SUPERHEATED VAPOR, FREON 22 (*Continued*)

Temp., °F.	Abs. Pressure 100 lb./in.^{2} Gage Pressure 85.3 lb./in.^{2} (Sat'n. Temp. 50.4° F.)			Abs. Pressure 110 lb./in.^{2} Gage Pressure 95.3 lb./in.^{2} (Sat'n. Temp. 56.1° F.)			Abs. Pressure 120 lb./in.^{2} Gage Pressure 105.3 lb./in.^{2} (Sat'n. Temp. 61.5° F.)		
t	*v*	*h*	*s*	*v*	*h*	*s*	*v*	*h*	*s*
(*at sat'n.*)	(*0.55049*)	(*109.83*)	(*0.21958*)	(*0.50046*)	(*110.30*)	(*0.21861*)	(*0.45855*)	(*110.71*)	(*0.21773*)
60	0.56508	111.31	0.22256	0.50610	110.90	0.21984	. . . .	. . . .	. . . . .
70	.58022	112.91	.22561	.52015	112.50	.22292	0.46979	112.08	0.22039
80	.59531	114.54	.22862	.53429	114.15	.22596	.48326	113.75	.22345
90	.61012	116.17	.23158	.54797	115.79	.22895	.49612	115.40	.22647
100	0.62494	117.80	0.23450	0.56170	117.44	0.23190	0.50886	117.07	0.22945
110	.63942	119.42	.23739	.57525	119.07	.23481	.52152	118.71	.23239
120	.65392	121.06	.24024	.58864	120.73	.23768	.53425	120.38	.23529
130	.66821	122.72	.24307	.60197	122.39	.24053	.54657	122.06	.23816
140	.68237	124.38	.24587	.61510	124.07	.24335	.55887	123.74	.24100
150	0.69646	126.05	0.24864	0.62813	125.74	0.24614	0.57105	125.43	0.24381
160	.71066	127.74	.25139	.64115	127.44	.24890	.58319	127.14	.24658
170	.72463	129.44	.25411	.65410	129.15	.25163	.59522	128.86	.24932
180	.73862	131.15	.25680	.66690	130.87	.25433	.60720	130.59	.25204
190	.75229	132.87	.25947	.67961	132.60	.25701	.61898	132.33	.25474
200	0.76604	134.60	0.26212	0.69215	134.34	0.25967	0.63068	134.07	0.25742
210	.77956	136.35	.26475	.70482	136.09	.26231	.64240	135.83	.26007
220	.79331	138.10	.26736	.71737	137.85	.26493	.65408	137.60	.26269
230	.80705	139.87	.26995	.72993	139.62	.26753	.66570	139.38	.26530
240	.82063	141.65	.27252	.74241	141.41	.27011	.67720	141.17	.26789
250	0.83426	143.44	0.27507	0.75496	143.20	0.27267	0.68877	142.97	0.27046
260	.84772	145.25	.27761	.76728	145.02	.27522	.70033	144.79	.27301
270	.86115	147.08	.28013	.77957	146.86	.27775	.71182	146.64	.27555
280	.87464	148.93	.28263	.79192	148.71	.28026	.72309	148.49	.27807
290	.88791	150.78	.28511	.80409	150.57	.28275	.73441	150.36	.28057
300	0.90106	152.64	0.28757	0.81623	152.44	0.28522	0.74563	152.23	0.28305
310	.91442	154.52	.29002	.82841	154.32	.28768	.75690	154.12	.28551
320	.92765	156.42	.29246	.84063	156.22	.29013	.76813	156.02	.28796
330	.94100	158.32	.29489	.85289	158.13	.29256	.77934	157.94	.29040
340	.95412	160.23	.29731	.86495	160.05	.29498	.79058	159.86	.29283
350	0.96737	162.16	0.29972	0.87712	161.98	0.29739	0.80178	161.80	0.29525
360	.98055	164.11	.30211	.88908	163.93	.29979	.81286	163.75	.29766
370	....	......	....	....	....	......	.82397	165.72	.30005

TABLE 2A–17. PROPERTIES OF SUPERHEATED VAPOR, FREON 22 (*Continued*)

Temp., °F.	Abs. Pressure 130 lb./in.^{2} Gage Pressure 115.3 lb./in.^{2} (Sat'n. Temp. 66.5° F.)			Abs. Pressure 140 lb./in.^{2} Gage Pressure 125.3 lb./in.^{2} (Sat'n. Temp. 71.3° F.)			Abs. Pressure 150 lb./in.^{2} Gage Pressure 135.3 lb./in.^{2} (Sat'n. Temp. 75.8° F.)		
t	*v*	*h*	*s*	*v*	*h*	*s*	*v*	*h*	*s*
(at sat'n.)	*(0.42275)*	*(111.07)*	*(0.21693)*	*(0.39185)*	*(111.40)*	*(0.21614)*	*(0.36483)*	*(111.69)*	*(0.21538)*
70	0 42718	111.64	0.21805				.	.....	......
80	.43982	113.33	.22113	0.40224	112.88	0.21388	0.36953	112.41	0.21665
90	.45198	115.00	.22417	.41412	114.59	.22195	.38096	114.15	.21980
100	0.46412	116.68	0.22717	0.42571	116 28	0 22498	0.39216	115.87	0.22289
110	.47609	118.34	.23013	.43687	117.96	.22797	.40300	117.57	.22592
120	.48789	120.03	.23305	.44826	119.66	.23092	.41393	119.29	.22890
130	.49964	121.72	.23594	.45931	121 37	.23384	.42447	121.01	.23185
140	.51123	123.41	.23880	.47035	123.07	.23672	.43492	122.73	.23476
150	0.52268	125.11	0.24163	0.48120	124 79	0.23957	0.44528	124.46	0.23763
160	.53411	126.83	.24442	.49210	126.52	.24238	.45559	126.20	.24046
170	.54541	128.56	.24718	.50268	128.26	.24516	.46574	127.95	.24326
180	.55662	130 30	.24991	.51323	130.00	.24791	.47571	129.71	.24603
190	.56773	132.05	.25262	.52360	131.76	.25064	.48557	131.47	.24877
200	0.57860	133.81	0.25531	0.53401	133.53	0.25334	0.49530	133.25	0.25148
210	.58951	135.57	.25797	.54436	135.30	.25601	.50513	135.04	.25416
220	.60049	137.35	.26061	.55459	137.09	.25866	.51485	136.83	.25682
230	.61138	139 13	.26323	.56485	138.88	.26129	.52451	138.63	.25946
240	.62211	140.93	.26583	.57492	140.69	.26390	.53405	140.44	.26208
250	0.63297	142.74	0.26841	0.58500	142.50	0.26649	0.54355	142.27	0.26468
260	.64365	144.56	.27097	.59509	144.34	.26906	.55302	144.11	.26726
270	.65433	146.41	.27351	.60512	146.19	.27161	.56250	145.97	.26982
280	.66487	148.28	.27603	.61504	148 06	.27414	.57177	147.84	.27236
290	.67540	150.14	.27854	.62484	149.93	.27665	.58109	149.72	.27488
300	0.68585	152.02	0.28103	0.63468	151.82	0.27915	0.59034	151.61	0.27738
310	.69647	153.92	.28350	.64456	153.71	.28163	.59965	153.51	.27986
320	.70687	155.83	.28596	.65437	155.63	.28409	.60895	155.43	.28233
330	.71738	157.74	.28841	.66410	157.55	.28654	.61811	157.36	.28479
340	.72773	159.67	.29084	.67387	159.48	.28898	.62780	159.29	.28724
350	0.73811	161.61	0.29326	0.68354	161.43	0.29141	0.63638	161.25	0.28967
360	.74845	163.57	.29567	.69325	163.39	.29383	.64542	163.21	.29209
370	.75875	165.54	.29807	.70292	165.37	.29623	.65449	165.19	.29449
380	....	... ..	....	.71250	167.36	.29862	.66352	167.19	.29688

TABLE 2A-17. PROPERTIES OF SUPERHEATED VAPOR, FREON 22 (*Continued*)

Temp., °F.	Abs. Pressure 160 lb./in.^{2} Gage Pressure 145.3 lb./in.^{2} (Sat'n. Temp. 80.1° F.)			Abs. Pressure 180 lb./in.^{2} Gage Pressure 165.3 lb./in.^{2} (Sat'n. Temp. 88.2° F.)			Abs. Pressure 200 lb./in.^{2} Gage Pressure 185.3 lb./in.^{2} (Sat'n. Temp. 95.6° F.)		
t	*v*	*h*	*s*	*v*	*h*	*s*	*v*	*h*	*s*
(at sat'n.)	*(0.34109)*	*(111.96)*	*(0.21462)*	*(0.30118)*	*(112.40)*	*(0.21319)*	*(0.26900)*	*(112.73)*	*(0.21182)*
90	0.35179	113.70	0.21776	0.30312	112.73	0.21386			
100	0.36269	115.44	0.22089	0.31354	114.53	0.21707	0.27336	113.55	0.21334
110	.37330	117.16	.22396	.32355	116.31	.22022	.28285	115.41	.21662
120	.38378	118.90	.22698	.33310	118.09	.22331	.29222	117.22	.21982
130	.39390	120.64	.22995	.34268	119.87	.22634	.30129	119.05	.22295
140	.40391	122.38	.23288	.35200	121.65	.22933	.31016	120.86	.22602
150	0.41380	124.13	0.23577	0.36113	123.43	0.23227	0.31893	122.69	0.22902
160	.42358	125.88	.23862	.37013	125.21	.23517	.32737	124.51	.23197
170	.43319	127.64	.24144	.37905	126.99	.23803	.33576	126.32	.23488
180	.44285	129.40	.24423	.38791	128.78	.24086	.34390	128.14	.23775
190	.45217	131.18	.24699	.39662	130.58	.24365	.35208	129.97	.24058
200	0.46152	132.97	0.24971	0.40511	132.39	0.24641	0.35994	131.80	0.24337
210	.47087	134.76	.25241	.41371	134.21	.24915	.36791	133.64	.24613
220	.48005	136.56	.25509	.42206	136.03	.25185	.37562	135.48	.24886
230	.48919	138.37	.25774	.43034	137.86	.25452	.38339	137.33	.25156
240	.49826	140.20	.26037	.43859	139.70	.25717	.39093	139.19	.25424
250	0.50730	142.03	0.26298	0.44678	141.55	0.25980	0.39851	141.06	0.25690
260	.51623	143.88	.26557	.45497	143.41	.26241	.40601	142.93	.25952
270	.52512	145.74	.26814	.46300	145.29	.26500	.41344	144.82	.26212
280	.53397	147.62	.27069	.47110	147.18	.26757	.42085	146.72	.26470
290	.54282	149.50	.27322	.47912	149.07	.27011	.42812	148.63	.26726
300	0.55162	151.40	0.27572	0.48697	150.97	0.27263	0.43505	150.55	0.26980
310	.56041	153.31	.27821	.49505	152.89	.27513	.44275	152.48	.27233
320	.56915	155.23	.28069	.50286	154.83	.27762	.44994	154.42	.27484
330	.57771	157.16	.28316	.51061	156.77	.28010	.45717	156.37	.27733
340	.58637	159.11	.28561	.51840	158.72	.28257	.46418	158.34	.27981
350	0.59501	161.06	0.28804	0.52628	160.69	0.28502	0.47128	160.31	0.28227
360	.60357	163.03	.29046	.53395	162.67	.28745	.47837	162.30	.28471
370	.61211	165.01	.29287	.54170	164.66	.28987	.48545	164.30	.28714
380	.62068	167.02	.29526	.54934	166.67	.29228	.49242	166.31	.28955
390	.62922	169.02	.29764	.55700	168.67	.29468	.49938	168.33	.29195
400	. ... .						0.50637	170.37	.29434

TABLE 2A–17. PROPERTIES OF SUPERHEATED VAPOR, FREON 22 (*Continued*)

Temp., °F.	Abs. Pressure 220 lb./in.^{2} Gage Pressure 205.3 lb./in.^{2} (Sat'n. Temp. 102.5° F.)			Abs. Pressure 240 lb./in.^{2} Gage Pressure 225.3 lb./in.^{2} (Sat'n. Temp. 108.9° F.)			Abs. Pressure 260 lb./in.^{2} Gage Pressure 245.3 lb./in.^{2} (Sat'n. Temp. 115.0° F.)		
t	*v*	*h*	*s*	*v*	*h*	*s*	*v*	*h*	*s*
(*at sat'n.*)	(*0.24247*)	(*112.97*)	(*0.21055*)	(*0.22020*)	(*113.03*)	(*0.20933*)	(*0.20129*)	(*113.22*)	(*0.20782*)
110	0.24977	114.42	0.21319	0.22073	113.31	0.20966		.	. . .
120	.25862	116.29	.21650	.23045	115.28	.21314	0.20658	114.25	0.20999
130	.26735	118.17	.21973	.23883	117.23	.21652	.21472	116.27	.21345
140	.27591	120.03	.22287	.24710	119.16	.21979	.22269	118.25	.21681
150	0.28426	121.91	0.22593	0.25514	121.09	0.22296	0.23034	120.24	0.22007
160	.29233	123.76	.22893	.26287	122.98	.22604	.23794	122.16	.22324
170	.30042	125.61	.23189	.27047	124.86	.22907	.24535	124.09	.22635
180	.30790	127.46	.23481	.27789	126.75	.23205	.25257	126.02	.22940
190	.31546	129.32	.23769	.28511	128.65	.23498	.25955	127.96	.23239
200	0.32292	131.19	0.24053	0.29217	130.56	0.23786	0.26625	129.90	0.23532
210	.33042	133.05	.24333	.29919	132.44	.24070	.27284	131.81	.23820
220	.33768	134.92	.24610	.30606	134.33	.24350	.27933	133.72	.24104
230	.34501	136.79	.24883	.31284	136 22	.24627	.28572	135.64	.24384
240	.35193	138.67	.25153	.31956	138.12	.24900	.29211	137.56	.24660
250	0.35903	140.56	0.25421	0.32616	140.04	0.25170	0.29840	139.50	0.24933
260	.36598	142.44	.25686	.33264	141.94	.25437	.30450	141.42	.25203
270	.37293	144.35	.25949	.33922	143.86	.25702	.31073	143.36	.25470
280	.37978	146.26	.26210	.34562	145.79	.25965	.31684	145.31	.25735
290	.38655	148.18	.26468	.35197	147.73	.26225	.32288	147.26	.25997
300	0.39334	150.11	0.26724	0.35824	149.67	0.26483	0.32871	149.23	0.26257
310	.40007	152.05	.26978	.36453	151.62	.26739	.33460	151.19	.26515
320	.40674	154.01	.27230	.37074	153.59	.26993	.34039	153.17	.26771
330	.41331	155.97	.27480	.37686	155.57	.27245	.34619	155.16	.27025
340	.41988	157.95	.27728	.38302	157.55	.27494	.35195	157.16	.27276
350	0.42642	159.93	0.27975	0.38916	159.55	0.27742	0.35771	159.16	0.27525
360	.43299	161.93	.28220	.39515	161.55	.27988	.36332	161.18	.27772
370	.43943	163.94	.28464	.40122	163.57	.28233	.36903	163.21	.28018
380	.44591	165.96	.28707	.40721	165.61	.28477	.37461	165.26	.28263
390	.45238	167.99	.28948	.41319	167.65	.28719	.38022	167.31	.28506
400	0.45880	170.04	0.29188	0.41917	169.70	0.28960	0.38582	169.37	0.28748
410	.46520	172.11	.29427	.42505	171.78	.29200	.39131	171.46	.28989
420	....	. . .	. .. .	... ..	.. . .	....	.39679	173.57	.29229

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TABLE 2A-18. PROPERTIES OF SATURATED VAPOR

Temp. °F. *t*	Pressure		Volume		Density		Enthalpy from −40°F.			Entropy from −40°F.		Temp. °F. *t*
	Absolute lbs./in.² *p*	Gage lbs./in.² *g.p.*	Liquid ft.³/lb. *v_f*	Vapor ft.³/lb. *v_g*	Liquid lbs./ft.³ $1/v_f$	Vapor lbs./ft.³ $1/v_g$	Liquid Btu./lb. h_f	Latent Btu./lb. h_{fg}	Vapor Btu./lb. h_g	Liquid Btu./lb °F. s_f	Vapor Btu./lb.°F. s_g	
−30	0.2987	29.31*	0.00947	82.26	105.64	0.01216	1.97	72.68	74.65	0.0047	0.1738	−30
−28	.3214	29.27*	.00948	76.81	105.50	.01302	2.36	72.57	74.93	.0056	.1737	−28
−26	.3458	29.22*	.00949	71.71	105.37	.01395	2.76	72.45	75.21	.0065	.1736	−26
−24	.3718	29.16*	.00950	66.99	105.23	.01493	3.16	72.33	75.49	.0074	.1735	−24
−22	.3995	29.11*	.00952	62.63	105.09	.01597	3.56	72.21	75.77	.0083	.1733	−22
−20	0.4288	29.05*	0.00953	58.61	104.96	0.01706	3.96	72.09	76.05	0.0092	0.1732	−20
−18	.4600	28.98*	.00954	54.88	104.82	.01822	4.36	71.98	76.34	.0101	.1731	−18
−16	.4931	28.92*	.00955	51.42	104.68	.01945	4.76	71.86	76.62	.0110	.1730	−16
−14	.5280	28.85*	.00957	48.23	104.54	.02074	5.16	71.74	76.90	.0119	.1729	−14
−12	.5652	28.77*	.00958	45.25	104.40	.02210	5.56	71.62	77.18	.0128	.1729	−12
−10	0.6046	28.69*	0.00959	42.48	104.26	0.02354	5.96	71.51	77.47	0.0137	0.1728	−10
− 8	.6462	28.60*	.00960	39.92	104.12	.02505	6.36	71.39	77.75	.0146	.1727	− 8
− 6	.6902	28.51*	.00962	37.54	103.98	.02664	6.76	71.27	78.03	.0155	.1726	− 6
− 4	.7369	28.42*	.00963	35.31	103.84	.02832	7.17	71.15	78.32	.0164	.1726	− 4
− 2	.7860	28.32*	.00964	33.24	103.70	.03009	7.57	71.03	78.60	.0173	.1725	− 2
0	0.8377	28.21*	0.00966	31.31	103.56	0.03194	7.98	70.92	78.89	0.0182	0.1725	0
2	.8924	28.10*	.00967	29.52	103.41	.03388	8.38	70.80	79.18	.0190	.1724	2
4	.9503	27.99*	.00968	27.84	103.27	.03592	8.78	70.68	79.46	.0199	.1724	4
5†	0.9802	27.92*	.00969	27.04	103.20	.03698	8.98	70.62	79.60	.0203	.1723	5†
6	1.011	27.86*	.00970	26.27	103.13	.03806	9.19	70.56	79.75	.0208	.1723	6
8	1.075	27.73*	.00971	24.81	102.98	.04031	9.59	70.44	80.03	.0216	.1723	8
10	1.142	27.60*	0.00972	23.45	102.84	0.04265	10.00	70.32	80.32	0.0225	0.1723	10
12	1.213	27.45*	.00974	22.17	102.69	.04511	10.41	70.20	80.61	.0234	.1722	12
14	1.288	27.30*	.00975	20.97	102.55	.04769	10.81	70.08	80.89	.0242	.1722	14
16	1.366	27.14*	.00977	19.84	102.40	.05040	11.22	69.96	81.18	.0251	.1722	16
18	1.448	26.97*	.00978	18.79	102.25	.05322	11.62	69.84	81.46	.0259	.1722	18

20	1.534	26.80*	0.00979	17.81	102.10	0.05616	12.03	69.72	81.75	0.0268	0.1722	20
22	1.624	26.61*	.00981	16.89	101.96	.05922	12.44	69.60	82.04	.0276	.1721	22
24	1.719	26.42*	.00982	16.02	101.81	.06243	12.85	69.48	82.33	.0285	.1721	24
26	1.818	26.22*	.00984	15.20	101.66	.06579	13.26	69.36	82.62	.0293	.1722	26
28	1.922	26.01*	.00985	14.43	101.51	.06929	13.67	69.24	82.91	.0302	.1722	28
30	2.031	25.79*	0.00987	13.71	101.36	0.07294	14.08	69.12	83.20	0.0310	0.1722	30
32	2.145	25.55*	.00988	13.03	101.21	.07675	14.49	69.00	83.49	.0318	.1722	32
34	2.264	25.31*	.00990	12.39	101.06	.08071	14.91	68.87	83.78	.0327	.1722	34
36	2.388	25.06*	.00991	11.79	100.91	.08483	15.32	68.75	84.07	.0335	.1722	36
38	2.519	24.79*	.00993	11.22	100.76	.08913	15.74	68.62	84.36	.0343	.1722	38
40	2.655	24.52*	0.00994	10.68	100.60	0.09361	16.16	68.50	84.65	0.0352	0.1723	40
42	2.797	24.23*	.00996	10.18	100.45	.09826	16.57	68.37	84.94	.0360	.1723	42
44	2.944	23.93*	.00997	9.703	100.30	.1031	16.99	68.25	85.24	.0368	.1723	44
46	3.098	23.61*	.00999	9.253	100.14	.1081	17.41	68.12	85.53	.0377	.1724	46
48	3.258	23.29*	.01000	8.830	99.99	.1133	17.82	68.00	85.82	.0385	.1724	48
50	3.427	22.94*	0.01002	8.426	99.83	0.1187	18.24	67.87	86.11	0.0393	0.1725	50
52	3.602	22.59*	.01003	8.044	99.68	.1243	18.66	67.74	86.40	.0401	.1726	52
54	3.784	22.22*	.01005	7.682	99.52	.1302	19.08	67.61	86.69	.0410	.1726	54
56	3.973	21.83*	.01006	7.342	99.37	.1362	19.50	67.48	86.98	.0418	.1727	56
58	4.170	21.43*	.01008	7.018	99.21	.1425	19.93	67.35	87.28	.0426	.1727	58
60	4.374	21.02*	0.01010	6.713	99.05	0.1490	20.35	67.22	87.57	0.0434	0.1728	60
62	4.586	20.59*	.01011	6.424	93.89	.1557	20.77	67.09	87.86	.0442	.1729	62
64	4.807	20.14*	.01013	6.149	98.73	.1626	21.19	66.96	88.15	.0450	.1729	64
66	5.036	19.67*	.01015	5.889	98.58	.1698	21.62	66.83	88.45	.0459	.1730	66
68	5.275	19.18*	.01016	5.640	98.42	.1773	22.05	66.69	88.74	.0467	.1731	68
70	5.523	18.68*	0.01018	5.404	98.26	0.1851	22.48	66.56	89.04	0.0475	0.1731	70
72	5.780	18.16*	.01019	5.180	98.10	.1931	22.90	66.43	89.33	.0483	.1732	72
74	6.042	17.62*	.01021	4.971	97.93	.2012	23.33	66.29	89.62	.0491	.1733	74
76	6.320	17.06*	.01023	4.769	97.77	.2097	23.76	66.16	89.92	.0499	.1734	76
78	6.607	16.47*	.01025	4.574	97.61	.2186	24.19	66.02	90.21	.0507	.1735	78

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* Inches of mercury below one atmosphere.

† Standard ton temperatures.

TABLE 2A-18. PROPERTIES OF SATURATED VAPOR, FREON 113 (*Continued*)

Temp. °F. t	Pressure		Volume		Density		Enthalpy from −40°F.			Entropy from −40°F.		Temp. °F. t
	Absolute lbs./in.² p	Gage lbs./in.² $g.p.$	Liquid ft.³/lb. V_f	Vapor ft.³/lb. V	Liquid lbs./ft.³ $1/V_f$	Vapor lbs./ft.³ $1/V$	Liquid Btu./lb. h	Latent Btu./lb. L	Vapor Btu./lb. H	Liquid Btu./lb.°F. s	Vapor Btu./lb.°F. S	
80	6.902	15.87*	0.01026	4.392	97.45	0.2277	24.63	65.88	90.51	0.0515	0.1736	80
82	7.208	15.25*	.01028	4.218	97.28	.2371	25.06	65.74	90.80	.0523	.1737	82
84	7.527	14.60*	.01030	4.051	97.12	.2468	25.49	65.60	91.09	.0531	.1738	84
86†	7.856	13.93*	.01031	3.893	96.96	.2569	25.93	65.46	91.39	.0539	.1739	86†
88	8.194	13.24*	.01033	3.742	96.79	.2672	26.36	65.32	91.68	.0547	.1740	88
90	8.545	12.53*	0.01035	3.600	96.63	0.2778	26.80	65.18	91.98	0.0555	0.1741	90
92	8.908	11.79*	.01037	3.463	96.46	.2888	27.24	65.04	92.28	.0563	.1742	92
94	9.281	11.03*	.01039	3.333	96.30	.3001	27.67	64.90	92.57	.0571	.1743	94
96	9.668	10.24*	.01040	3.208	96.13	.3117	28.11	64.75	92.86	.0578	.1744	96
98	10.07	9.42*	.01042	3.089	95.96	.3237	28.55	64.60	93.15	.0586	.1745	98
100	10.48	8.59*	0.01044	2.976	95.79	0.3360	28.99	64.46	93.45	0.0594	0.1746	100
102	10.91	7.71*	.01046	2.867	95.63	.3488	29.44	64.31	93.75	.0602	.1747	102
104	11.35	6.82*	.01048	2.762	95.46	.3620	29.89	64.16	94.05	.0610	.1748	104
106	11.81	5.88*	.01050	2.662	95.29	.3756	30.33	64.01	94.34	.0618	.1750	106
108	12.28	4.93*	.01051	2.567	95.12	.3896	30.78	63.86	94.64	.0626	.1751	108
110	12.76	3.95*	0.01053	2.477	94.95	0.4038	31.22	63.71	94.93	0.0634	0.1752	110
112	13.25	2.95*	.01055	2.391	94.78	.4182	31.67	63.56	95.23	.0641	.1753	112
114	13.76	1.91*	.01057	2.308	94.61	.4333	32.12	63.40	95.52	.0649	.1755	114
116	14.29	0.83*	.01059	2.228	94.43	.4489	32.57	63.25	95.82	.0657	.1756	116
118	14.84	0.14	.01061	2.151	94.26	.4649	33.03	63.09	96.12	.0665	.1757	118
120	15.40	0.70	0.01063	2.078	94.09	0.4813	33.48	62.93	96.41	0.0673	0.1758	120
122	15.97	1.27	.01065	2.008	93.92	.4981	33.93	62.78	96.71	.0680	.1760	122
124	16.56	1.86	.01067	1.941	93.74	.5153	34.38	62.62	97.00	.0688	.1761	124
126	17.17	2.47	.01069	1.876	93.57	.5330	34.83	62.46	97.29	.0696	.1763	126
128	17.80	3.10	.01071	1.814	93.39	.5514	35.29	62.30	97.59	.0704	.1764	128

130	18.45	3.74	0.01073	1.754	93.22	0.5702	35.75	62.14	97.89	0.0712	0.1765	130
132	19.11	4.41	.01075	1.697	93.04	.5894	36.21	61.97	98.18	.0719	.1767	132
134	19.79	5.09	.01077	1.642	92.86	.6091	36.67	61.80	98.47	.0727	.1768	134
136	20.48	5.78	.01079	1.590	92.69	.6290	37.13	61.64	98.77	.0735	.1770	136
138	21.19	6.49	.01081	1.540	92.51	.6494	37.59	61.48	99.06	.0742	.1771	138
140	21.93	7.23	0.01083	1.491	92.33	0.6707	38.05	61.31	99.36	0.0750	0.1773	140
142	22.69	7.99	.01085	1.444	92.15	.6926	38.52	61.13	99.65	.0758	.1774	142
144	23.47	8.77	.01087	1.399	91.98	.7150	38.98	60.96	99.94	.0765	.1775	144
146	24.27	9.57	.01089	1.355	91.80	.7379	39.45	60.79	100.24	.0773	.1777	146
148	25.09	10.39	.01092	1.313	91.62	.7615	39.92	60.61	100.53	.0781	.1778	148
150	25.93	11.23	0.01094	1.273	91.44	0.7856	40.38	60.44	100.82	0.0789	0.1780	150
152	26.79	12.09	.01096	1.234	91.25	.8102	40.85	60.27	101.11	.0796	.1782	152
154	27.67	12.97	.01098	1.197	91.07	.8353	41.32	60.09	101.41	.0804	.1783	154
156	28.56	13.86	.01100	1.162	90.89	.8608	41.79	59.91	101.70	.0812	.1785	156
158	29.48	14.78	.01102	1.128	90.71	.8869	42.26	59.73	101.99	.0819	.1786	158
160	30.44	15.74	0.01105	1.094	90.53	0.9141	42.74	59.55	102.29	0.0827	0.1788	160
170	35.53	20.83	.01116	0.9442	89.60	1.059	45.12	58.62	103.74	.0865	.1796	170
180	41.22	26.52	.01128	.8193	88.67	1.221	47.53	57.66	105.19	.0903	.1804	180
190	47.60	32.90	.01140	.7134	87.72	1.402	49.97	56.66	106.63	.0940	.1813	190
200	54.66	39.96	.01153	.6241	86.76	1.602	52.45	55.62	108.07	.0978	.1821	200
210	62.50	47.80	.01166	.5477	85.79	1.826	54.96	54.54	109.50	.1015	.1830	210
220	71.07	56.37	0.01179	0.4827	84.80	2.072	57.49	53.43	110.92	0.1052	0.1839	220

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* Inches of mercury below one atmosphere.
† Standard ton temperatures.

TABLE 2A-19. PROPERTIES OF SUPERHEATED VAPOR, FREON 113

Temp. ° F.	Abs. Pressure 0.3 lb./in.² Gauge Pressure 29.31 in. Vac. (Sat'n. Temp. –29.9° F.)			Abs. Pressure 0 4 lb./in.² Gauge Pressure 29.11 in. Vac. (Sat'n. Temp. –22.0° F.)			Abs. Pressure 0.5 lb./in.² Gauge Pressure 28.90 in. Vac. (Sat'n. Temp. –15.6° F.)			Abs. Pressure 0.6 lb./in.² Gauge Pressure 28.70 in. Vac. (Sat'n. Temp. –10.2° F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(At sat'n.)	(81.95)	(74.66)	(0.1738)	(62.55)	(75 77)	(0.1733)	(50 79)	(76.68)	(0.1730)	(42.81)	(77.44)	(0.1728)
–20	83.83	76.06	0.1770	62.82	76.05	0.1740	.....	.....	.....	.....	.....	.....
–10	85.74	77.48	.1802	64.25	77.47	.1772	51.43	77.47	0.1748	42.83	77.47	0.1729
0	87.65	78.91	0.1834	65.68	78.90	0.1803	52.58	78.90	0.1779	43.79	78.90	0.1760
10	89.55	80.35	.1865	67.11	80.34	.1834	53.72	80.34	.1810	44.74	80.34	.1791
20	91.46	81.80	.1895	68.63	81.80	.1865	54.87	81.79	.1841	45.70	81.79	.1822
30	93.37	83.26	.1925	70.06	83.26	.1895	56.01	83.26	.1871	46.65	83.25	.1852
40	95.27	84.74	.1955	71.49	84.74	.1925	57.16	84.73	.1901	47.61	84.73	.1882
50	97.18	86.23	0.1985	72.92	86.22	0.1954	58.31	86.22	0.1931	48.56	86.22	0.1911
60	99.09	87.73	.2014	74.35	87.72	.1983	59.47	87.72	.1960	49.52	87.72	.1940
70	101.0	89.24	.2043	75.79	89.23	.2012	60.63	89.23	.1989	50.47	89.23	.1969
80	102.9	90.76	.2071	77.22	90.76	.2041	61.78	90.75	.2017	51.43	90.75	.1998
90	104.8	92.29	.2099	78.65	92.29	.2069	62.93	92.28	.2045	52.38	92.28	.2026
100	106.7	93.83	0.2127	80.08	93.83	0.2097	64.07	93.83	0.2073	53.34	93.82	0.2054
110	108.6	95.40	.2155	81.51	95.39	.2124	65.21	95.39	.2101	54.31	95.39	.2081
120	110.5	96.97	.2182	82.94	96.96	.2152	66.36	96.96	.2128	55.27	96.96	.2109
130	112.4	98.55	.2209	84.37	98.54	.2179	67.51	98.54	.2155	56.22	98.54	.2136
140	114.3	100.14	.2236	85.80	100.13	.2206	68.65	100.13	.2182	57.18	100.13	.2162
150	116.3	101.74	0.2262	87.23	101.74	0.2232	69.80	101.73	0.2208	58.13	101.73	0.2189
160	118.2	103.36	.2289	88.66	103.35	.2258	70.94	103.35	.2234	59.09	103.34	.2215
170	120.1	104.98	.2315	90.10	104.98	.2284	72.09	104.98	.2260	60.04	104.97	.2241
180	122.0	106.62	.2341	91.53	106.62	.2310	73.23	106.61	.2286	60.99	106.61	.2267
190	124.0	108.27	.2366	92.96	108.27	.2336	74.38	108.26	.2312	61.95	108.26	.2293
200	125.9	109.93	0.2392	94.39	109.93	0.2361	75.52	109.92	0.2337	62.90	109.92	0.2318
210	127.8	111.61	.2417	95.82	111.61	.2386	76.67	111.60	.2363	63.85	111.60	.2343
220	129.7	113.30	.2442	97.25	113.30	.2411	77.81	113.29	.2388	64.81	113.29	.2368
230	131.6	115.00	.2467	98.68	114.99	.2436	78.96	114.99	.2412	65.76	114.99	.2393
240	133.6	116.71	.2491	100.1	116.70	.2461	80.10	116.70	.2437	66.71	116.70	.2418
250	135.5	118.42	0.2516	101.5	118.42	0.2485	81.25	118.42	0.2461	67.67	118.41	0.2442
260	137.4	120.15	.2540	103.0	120.15	.2509	82.39	120.15	.2486	68.62	120.14	.2466
270	139.3	121.89	.2564	104.4	121.88	.2533	83.54	121.88	.2510	69.57	121.87	.2490
280	141.2	123.64	0.2588	105.9	123.63	0.2557	84.68	123.63	.2533	70.53	123.62	.2514
290	.....	.....	.....	.....	.....	.....	85.83	125.40	0.2557	71.48	125.39	0.2538

Temp. °F.	Abs. Pressure 0.7 lb./in.² Gauge Pressure 28.50 in. Vac. (Sat'n. Temp. –5.6° F.)			Abs. Pressure 0 8 lb /in.² Gauge Pressure 28 29 in. Vac. (Sat'n. Temp. –1.5° F.)			Abs. Pressure 0.9 lb./in.² Gauge Pressure 28.09 in. Vac. (Sat'n. Temp. +2.3° F.)			Abs. Pressure 1.0 lb./in.² Gauge Pressure 27.88 in. Vac. (Sat'n. Temp. 5.6° F.)		
(At sat'n.)	(37.05)	(78 10)	(0.1726)	(32.71)	(78.68)	(0.1725)	(29.30)	(79.22)	(0.1724)	(26.54)	(79.69)	(0.1723)
0	37.49	78.90	0.1743	32.81	78.89	0.1729	.....	.....	.....	.....	.....	.....
10	38.32	80.34	.1774	33.53	80.33	.1760	29.79	80.33	0.1748	26.79	80.32	0.1737
20	39.15	81.79	.1805	34.25	81.78	.1791	30.43	81.78	.1779	27.38	81.78	.1768
30	39.98	83.25	.1835	34.97	83.25	.1821	31.07	83.24	.1809	27.96	83.24	.1798
40	40.80	84.72	.1865	35.69	84.72	.1851	31.71	84.72	.1839	28.53	84.71	.1828
50	41.62	86.21	0.1895	36.41	86.21	0.1881	32.35	86.20	0.1868	29.10	86.20	0.1857
60	42.43	87.71	.1924	37.13	87.71	.1910	32.99	87.70	.1897	29.67	87.70	.1886
70	43.25	89.22	.1953	37.85	89.22	.1939	33.63	89.21	.1926	30.25	89.21	.1915
80	44.07	90.74	.1981	38.57	90.74	.1967	34.27	90.74	.1955	30.82	90.73	.1943
90	44.89	92.28	.2009	39.29	92.27	.1995	34.91	92.27	.1983	31.39	92.27	.1972
100	45.71	93.82	0.2037	40.01	93.82	0.2023	35.55	93.81	0.2011	31.97	93.81	0.2000
110	46.53	95.38	.2065	40.72	95.38	.2051	36.19	95.37	.2038	32.56	95.37	.2027
120	47.35	96.95	.2092	41.44	96.95	.2078	36.83	96.94	.2066	33.14	96.94	.2054
130	48.18	98.53	.2119	42.16	98.53	.2105	37.47	98.52	.2093	33.71	98.52	.2081
140	49.00	100.12	.2146	42.88	100.12	.2132	38.11	100.12	.2119	34.28	100.11	.2108
150	49.83	101.73	0.2172	43.60	101.72	0.2158	38.75	101.72	0.2146	34.85	101.72	0.2135
160	50.65	103.34	.2199	44.32	103.34	.2185	39.39	103.33	.2172	35.42	103.33	.2161
170	51.47	104.97	.2225	45.04	104.96	.2211	40.03	104.96	.2198	35.99	104.96	.2187
180	52.29	106.61	.2251	45.75	106.60	.2236	40.67	106.60	.2224	36.57	106.60	.2213
190	53.10	108.26	.2276	46.47	108.25	.2262	41.31	108.25	.2249	37.15	108.25	.2238
200	53.92	109.92	0.2302	47.18	109.91	0.2288	41.94	109.91	0.2275	37.73	109.91	0.2264
210	54.74	111.60	.2327	47.90	111.59	.2313	42.57	111.59	.2300	38.30	111.59	.2289
220	55.56	113.29	.2352	48.61	113.28	.2338	43.21	113.28	.2325	38.88	113.28	.2314
230	56.37	114.98	.2377	49.33	114.98	.2363	43.84	114.98	.2350	39.46	114.97	.2339
240	57.19	116.69	.2401	50.04	116.69	.2387	44.48	116.69	.2375	40.03	116.68	.2363
250	58.01	118.41	0.2426	50.76	118.41	0.2412	45.12	118.40	0.2399	40.60	118.40	0.2388
260	58.83	120.14	.2450	51.47	120.13	.2436	45.75	120.13	.2423	41.18	120.13	.2412
270	59.64	121.87	.2474	52.19	121.86	.2460	46.39	121.86	.2447	41.75	121.86	.2436
280	60.46	123.62	.2498	52.90	123.61	.2484	47.02	123.61	.2471	42.32	123.62	.2460
290	61.28	125.39	.2522	53.62	125.38	.2507	47.66	125.38	.2495	42.89	125.38	.2484
300	62.10	127.18	0.2545	54.34	127.17	0.2531	48.30	127.17	0.2518	43.46	127.16	0.2507
310	....	.....	.....	.....	.....	.....	48.93	128.97	0.2542	44.04	128.96	0.2531

TABLE 2A–19. PROPERTIES OF SUPERHEATED VAPOR, FREON 113 (*Continued*)

Temp. ° F.	Abs Pressure 1.1 lb./in.² Gauge Pressure 27.68 in Vac. (Sat'n. Temp. 8.7° F.)			Abs. Pressure 1.2 lb /in² Gauge Pressure 27.48 in. Vac. (Sat'n. Temp. 11.6° F.)			Abs. Pressure 1.3 lb./in² Gauge Pressure 27.27 in. Vac. (Sat'n. Temp 14.3° F.)			Abs. Pressure 1.4 lb./in.² Gauge Pressure 27.07 in. Vac. (Sat'n. Temp. 16.8° F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(At sat'n.)	(24.29)	(80.13)	(0.1723)	(22.40)	(80.55)	(0.1722)	(20.79)	(80.93)	(0.1722)	(19.40)	(81.30)	(0.1722)
10	24.35	80.32	0.1726	.....	.....	.....	.....	.....	.....	.....	.....	.....
20	24.87	81.77	.1757	22.80	81.77	0.1748	21.03	81.76	0.1740	19.52	81.76	0.1731
30	25.39	83.24	.1787	23.28	83.23	.1778	21.47	83.23	.1770	19.93	83.23	.1762
40	25.91	84.71	.1817	23.75	84.71	.1808	21.91	84.70	.1800	20.35	84.70	.1792
50	26.43	86.20	0.1847	24.23	86.19	0.1837	22.36	86.19	0.1829	20.76	86.19	0.1821
60	26.96	87.70	.1876	24.71	87.69	.1866	22.80	87.69	.1858	21.17	87.69	.1850
70	27.49	89.21	.1905	25.19	89.20	.1895	23.24	89.20	.1887	21.58	89.20	.1879
80	28.01	90.73	.1933	25.67	90.72	.1924	23.68	90.72	.1915	21.99	90.72	.1907
90	28.53	92.26	.1961	26.15	92.26	.1952	24.13	92.26	.1944	22.40	92.25	.1935
100	29.05	93.81	0.1989	26.63	93.80	0.1980	24.58	93.80	0.1971	22.81	93.80	0.1963
110	29.57	95.37	.2017	27.11	95.36	.2007	25.02	95.36	.1999	23.22	95.36	.1991
120	30.09	96.94	.2044	27.59	96.93	.2035	25.46	96.93	.2026	23.63	96.93	.2018
130	30.62	98.52	.2071	28.07	98.51	.2062	25.90	98.51	.2053	24.04	98.51	.2045
140	31.15	100.11	.2098	28.55	100.10	.2089	26.34	100.10	.2080	24.45	100.10	.2072
150	31.68	101.71	0.2124	29.03	101.71	0.2115	26.78	101.70	0.2106	24.86	101.70	0.2099
160	32.20	103.33	.2151	29.51	103.32	.2141	27.23	103.32	.2133	25.27	103.32	.2125
170	32.72	104.95	.2177	29.99	104.95	.2167	27.68	104.95	.2159	25.68	104.94	.2151
180	33.24	106.59	.2202	30.47	106.59	.2193	28.12	106.59	.2185	26.10	106.58	.2177
190	33.76	108.24	.2228	30.95	108.24	.2219	28.56	108.24	.2211	26.52	108.23	.2202
200	34.28	109.90	0.2253	31.43	109.90	0.2244	29.00	109.90	0.2236	26.93	109.89	0.2228
210	34.80	111.58	.2279	31.91	111.58	.2270	29.44	111.58	.2261	27.34	111.57	.2253
220	35.32	113.27	.2304	32.39	113.27	.2295	29.88	113.27	.2286	27.75	113.26	.2278
230	35.85	114.97	.2329	32.87	114.97	.2319	30.32	114.96	.2311	28.16	114.96	.2303
240	36.37	116.68	.2353	33.35	116.68	.2344	30.76	116.67	.2335	28.57	116.67	.2328
250	36.90	118.40	0.2378	33.83	118.39	0.2368	31.20	118.39	0.2360	28.98	118.39	0.2352
260	37.43	120.13	.2402	34.31	120.12	.2393	31.64	120.12	.2384	29.39	120.12	.2376
270	37.95	121.86	.2426	34.79	121.86	.2417	32.08	121.86	.2408	29.80	121.85	.2400
280	38.47	123.61	.2450	35.26	123.61	.2441	32.53	123.61	.2432	30.21	123.60	.2424
290	38.99	125.38	.2474	35.74	125.38	.2464	32.98	125.37	.2456	30.62	125.37	.2448
300	39.51	127.16	0.2497	36.22	127.16	0.2488	33.43	127.16	0.2479	31.03	127.16	0.2471
310	40.03	128.96	0.2521	36.69	128.96	.2511	33.88	128.96	.2503	31.44	128.95	.2495
320	.....	.....	.....	37.17	130.76	0.2535	34.32	130.76	0.2526	31.85	130.75	0.2518

Temp. °F.	Abs. Pressure 1.6 lb./in.² Gauge Pressure 26.66 in. Vac. (Sat'n. Temp. 21.5° F.)			Abs. Pressure 1.8 lb./in.² Gauge Pressure 26.26 in. Vac. (Sat'n. Temp. 25.6° F.)			Abs. Pressure 2.0 lb./in.² Gauge Pressure 25.85 in. Vac. (Sat'n. Temp. 29.4° F.)			Abs. Pressure 2.2 lb./in.² Gauge Pressure 25.44 in. Vac. (Sat'n. Temp. 32.9°F.)		
(At sat'n.)	(17.13)	(81.97)	(0.1721)	(15.35)	(82.57)	(0.1722)	(13.91)	(83.12)	(0.1722)	(12.74)	(83.62)	(0.1722)
30	17.43	83.22	0.1747	15.49	83.21	0.1735	13.92	83.20	0.1724	.....	.....	.....
40	17.79	84.69	.1777	15.81	84.68	.1765	14.21	84.68	.1753	12.92	84.67	0.1743
50	18.15	86.18	0.1807	16.13	86.17	0.1794	14.50	86.16	0.1783	13.18	86.16	0.1773
60	18.51	87.68	.1836	16.45	87.67	.1823	14.79	87.66	.1812	13.44	87.66	.1802
70	18.87	89.19	.1865	16.77	89.18	.1852	15.08	89.17	.1841	13.70	89.17	.1831
80	19.23	90.71	.1893	17.09	90.70	.1881	15.37	90.69	.1869	13.96	90.69	.1859
90	19.59	92.24	.1921	17.41	92.24	.1909	15.66	92.23	.1898	14.22	92.22	.1887
100	19.95	93.79	0.1949	17.73	93.78	0.1937	15.95	93.77	0.1926	14.48	93.77	0.1915
110	20.31	95.35	.1977	18.05	95.34	.1964	16.24	95.33	.1953	14.75	95.33	.1943
120	20.67	96.92	.2004	18.37	96.91	.1992	16.53	96.90	.1980	15.02	96.90	.1970
130	21.03	98.50	.2031	18.69	98.49	.2019	16.82	98.49	.2007	15.28	98.49	.1997
140	21.39	100.09	.2058	19.01	100.08	.2045	17.11	100.09	.2034	15.54	100.08	.2024
150	21.75	101.69	0.2084	19.33	101.69	0.2072	17.39	101.69	0.2061	15.81	101.68	0.2051
160	22.11	103.31	.2111	19.65	103.31	.2098	17.68	103.31	.2087	16.07	103.30	.2077
170	22.47	104.94	.2137	19.97	104.93	.2124	17.96	104.93	.2113	16.33	104.93	.2103
180	22.83	106.58	.2163	20.29	106.57	.2150	18.25	106.57	.2139	16.59	106.56	.2129
190	23.19	108.22	.2188	20.61	108.22	.2176	18.54	108.22	.2164	16.85	108.21	.2154
200	23.55	109.89	0.2214	20.93	109.88	0.2201	18.83	109.88	0.2190	17.11	109.88	0.2180
210	23.91	111.57	.2239	21.25	111.56	.2226	19.12	111.56	.2215	17.38	111.55	.2205
220	24.27	113.26	.2264	21.57	113.25	.2251	19.40	113.24	.2240	17.64	113.24	.2230
230	24.63	114.95	.2289	21.89	114.95	.2276	19.69	114.94	.2265	17.90	114.93	.2255
240	24.99	116.66	.2313	22.21	116.66	.2301	19.97	116.65	.2290	18.16	116.64	.2279
250	25.35	118.38	0.2338	22.53	118.38	0.2325	20.26	118.37	0.2314	18.42	118.36	0.2304
260	25.71	120.11	.2362	22.85	120.11	.2349	20.55	120.10	.2338	18.68	120.09	.2328
270	26.07	121.85	.2386	23.17	121.84	.2373	20.84	121.84	.2362	18.94	121.83	.2352
280	26.43	123.60	.2410	23.49	123.59	.2397	21.13	123.59	.2386	19.20	123.58	.2376
290	26.78	125.37	.2434	23.81	125.36	.2421	21.42	125.36	.2409	19.47	125.35	.2400
300	27.14	127.16	0.2457	24.12	127.15	0.2445	21.71	127.15	0.2433	19.74	127.14	0.2423
310	27.50	128.95	.2481	24.44	128.94	.2468	22.00	128.94	.2457	20.00	128.93	.2447
320	27.86	130.75	.2504	24.76	130.74	.2491	22.28	130.74	.2480	20.26	130.73	.2470
330	28.23	132.56	0.2527	25.08	132.56	0.2514	22.57	132.55	0.2503	20.52	132.55	.2493
340	.....	.....	.....	.....	.....	.....	.....	.....	.....	20.78	134.37	0.2516

TABLE 2A-19. PROPERTIES OF SUPERHEATED VAPOR, FREON 113 (*Continued*)

Temp. °F	Abs. Pressure 2.4 lb./in.^{2} Gauge Pressure 25.04 in. Vac. (Sat'n. Temp. 36.2° F.)			Abs. Pressure 2.6 lb./in.^{2} Gauge Pressure 24.63 in. Vac. (Sat'n Temp. 39.2° F.)			Abs. Pressure 2.8 lb./in.^{2} Gauge Pressure 24.22 in. Vac. (Sat'n. Temp. 42.0° F.)			Abs. Pressure 3.0 lb./in.^{2} Gauge Pressure 23.81 in. Vac. (Sat'n. Temp. 44.7° F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(At sat'n)	(11.74)	(84.10)	(0.1722)	(10.89)	(84.53)	(0.1723)	(10.17)	(84.94)	(0.1723)	(9.537)	(85.34)	(0.1723)
40	11.84	84.66	0.1734	10.91	84.65	0.1725	.....	.....	.....	.....	.....	.....
50	12.08	86.15	0.1763	11.13	86.14	0.1755	10.33	86.13	0.1747	9.637	86.12	0.1739
60	12.32	87.65	.1792	11.35	87.64	.1784	10.54	87.63	.1776	9.831	87.62	.1769
70	12.56	89.16	.1821	11.58	89.15	.1813	10.75	89.14	.1805	10.02	89.13	.1797
80	12.80	90.68	.1850	11.80	90.67	.1841	10.95	90.66	.1833	10.22	90.66	.1826
90	13.04	92.21	.1878	12.02	92.21	.1869	11.16	92.20	.1861	10.41	92.19	.1854
100	13.28	93.76	0.1906	12.24	93.75	0.1897	11.37	93.74	0.1889	10.60	93.74	0.1882
110	13.52	95.32	.1934	12.47	95.31	.1925	11.58	95.30	.1917	10.80	95.30	.1910
120	13.76	96.89	.1961	12.69	96.88	.1952	11.79	96.87	.1944	10.99	96.87	.1937
130	14.00	98.48	.1988	12.91	98.47	.1979	11.99	98.46	.1971	11.18	98.46	.1964
140	14.24	100.07	.2015	13.13	100.06	.2006	12.20	100.06	.1998	11.38	100.05	.1991
150	14.48	101.68	0.2041	13.36	101.67	0.2033	12.40	101.66	0.2025	11.57	101.65	0.2017
160	14.72	103.29	.2068	13.58	103.28	.2059	12.61	103.28	.2051	11.76	103.27	.2044
170	14.96	104.92	.2094	13.80	104.91	.2085	12.82	104.90	.2077	11.95	104.90	.2070
180	15.20	106.56	.2099	14.02	106.55	.2111	13.02	106.54	.2103	12.15	106.54	.2095
190	15.44	108.21	.2145	14.25	108.20	.2137	13.23	108.19	.2129	12.34	108.19	.2121
200	15.68	109.87	0.2171	14.47	109.86	0.2162	13.44	109.86	0.2154	12.53	109.85	0.2147
210	15.93	111.54	.2196	14.69	111.54	.2187	13.65	111.54	.2179	12.72	111.53	.2172
220	16.17	113.23	.2221	14.91	113.22	.2212	13.85	113.23	.2204	12.92	113.22	.2197
230	16.41	114.93	.2246	15.13	114.92	.2237	14.05	114.92	.2229	13.11	114.92	.2222
240	16.65	116.64	.2270	15.35	116.63	.2262	14.26	116.63	.2254	13.30	116.63	.2246
250	16.89	118.35	0.2295	15.58	118.35	0.2286	14.46	118.35	0.2278	13.49	118.35	0.2271
260	17.13	120.08	.2319	15.80	120.08	.2310	14.67	120.08	.2302	13.68	120.08	.2295
270	17.37	121.82	.2343	16.02	121.82	.2334	14.88	121.82	.2326	13.87	121.82	.2319
280	17.61	123.58	.2367	16.24	123.57	.2358	15.09	123.57	.2350	14.06	123.57	.2343
290	17.85	125.35	.2391	16.46	125.34	.2382	15.29	125.34	.2374	14.26	125.33	.2367
300	18.09	127.14	0.2414	16.68	127.13	0.2406	15.50	127.13	0.2398	14.46	127.11	0.2390
310	18.33	128.93	.2437	16.90	128.92	.2429	15.70	128.92	.2421	14.65	128.91	.2414
320	18.57	130.73	.2461	17.12	130.72	.2452	15.90	130.73	.2444	14.84	130.71	.2437
330	18.81	132.54	.2484	17.34	132.54	.2475	16.11	132.54	.2467	15.03	132.52	.2460
340	19.05	134.36	0.2507	17.56	134.36	0.2498	16.31	134.36	.2490	15.22	134.35	.2483
350	.....	.....	.....	.....	.....	.....	16.52	136.20	0.2513	15.41	136.19	0.2505

Temp. °F.	Abs. Pressure 3.2 lb./in.^{2} Gauge Pressure 23 41 in. Vac. (Sat'n. Temp. 47.3° F.)			Abs. Pressure 3.4 lb./in.^{2} Gauge Pressure 23.00 in. Vac. (Sat'n. Temp. 49.7° F.)			Abs. Pressure 3.6 lb./in.^{2} Gauge Pressure 22 59 in. Vac. (Sat'n. Temp. 52.0° F.)			Abs. Pressure 3.8 lb./in.^{2} Gauge Pressure 22 19 in. Vac. (Sat'n. Temp 54.2° F.)		
(At sat'n)	(8.983)	(85.71)	(0.1724)	(8.489)	(86.06)	(0.1725)	(8.047)	(86.40)	(0.1725)	(7.653)	(86.72)	(0.1726)
50	9.030	86.12	0.1733	8.493	86.11	0.1726	....	....	.....	....	....	.....
60	9.209	87.62	.1762	8.665	87.61	.1755	8.177	87.60	0.1749	7.742	87.59	0.1743
70	9.391	89.13	.1791	8.837	89.12	.1784	8.338	89.11	.1778	7.895	89.10	.1772
80	9.573	90.65	.1819	9.009	90.64	.1813	8.499	90.63	.1806	8.048	90.62	.1800
90	9.755	92.18	.1847	9.181	92.18	.1841	8.659	92.17	.1834	8.201	92.16	.1829
100	9.938	93.73	0.1875	9.353	93.72	0.1869	8.819	93.71	0.1862	8.354	93.71	0.1857
110	10.12	95.29	.1903	9.525	95.28	.1896	8.980	95.27	.1890	8.506	95.27	.1884
120	10.30	96.86	.1930	9.697	96.85	.1924	9.141	96.84	.1917	8.659	96.84	.1911
130	10.48	98.45	.1957	9.869	98.44	.1951	9.305	98.43	.1944	8.812	98.43	.1938
140	10.66	100.04	.1984	10.03	100.03	.1977	9.466	100.03	.1971	8.965	100.02	.1965
150	10.84	101.65	0.2010	10.20	101.64	0.2004	9.627	101.63	0.1998	9.118	101.62	0.1992
160	11.02	103.26	.2037	10.37	103.26	.2030	9.788	103.25	.2024	9.271	103.24	.2018
170	11.20	104.89	.2063	10.54	104.89	.2056	9.948	104.88	.2050	9.423	104.87	.2044
180	11.38	106.54	.2089	10.71	106.53	.2082	10.11	106.53	.2076	9.576	106.52	.2070
190	11.56	108.19	.2114	10.88	108.18	.2108	10.27	108.18	.2102	9.729	108.17	.2096
200	11.74	109.85	0.2140	11.05	109.85	0.2133	10.43	109.84	0.2127	9.882	109.83	0.2121
210	11.92	111.53	.2165	11.22	111.52	.2159	10.59	111.51	.2153	10.03	111.51	.2147
220	12.10	113.21	.2190	11.39	113.21	.2184	10.75	113.20	.2178	10.19	113.19	.2172
230	12.28	114.91	.2215	11.56	114.90	.2208	10.91	114.90	.2202	10.34	114.89	.2196
240	12.47	116.62	.2240	11.73	116.61	.2233	11.07	116.61	.2227	10.49	116.60	.2221
250	12.65	118.34	0.2264	11.90	118.33	0.2257	11.23	118.32	0.2252	10.64	118.32	0.2245
260	12.83	120.06	.2288	12.07	120.05	.2282	11.40	120.05	.2276	10.79	120.04	.2270
270	13.01	121.80	.2312	12.24	121.79	.2306	11.56	121.79	.2300	10.95	121.78	.2294
280	13.19	123.55	.2336	12.41	123.55	.2330	11.72	123.54	.2324	11.10	123.53	.2318
290	13.37	125.32	.2360	12.58	125.32	.2353	11.88	125.31	.2347	11.25	125.30	.2341
300	13.56	127.11	0.2383	12.75	127.11	0.2377	12.04	127.10	0.2371	11.40	127.09	0.2365
310	13.74	128.90	.2407	12.92	128.90	.2400	12.20	128.89	.2394	11.55	128.89	.2388
320	13.92	130.70	.2430	13.09	130.70	.2423	12.36	130.69	.2417	11.70	130.69	.2412
330	14.09	132.52	.2453	13.26	132.51	.2446	12.52	132.51	.2441	11.85	132.50	.2435
340	14.27	134.34	.2476	13.43	134.34	.2469	12.68	134.33	.2464	12.00	134.33	.2458
350	14.45	136.18	0.2499	13.60	136.18	0.2492	12.84	136.17	0.2486	12.15	136.17	0.2481
360	....	.....	.....	....	.....	.....	13.00	138.02	0.2509	12.31	138.01	0.2508

TABLE 2A-19. PROPERTIES OF SUPERHEATED VAPOR, FREON 113 (*Continued*)

Temp. °F.	Abs. Pressure 4.0 lb./in.² Gauge Pressure 21.78 in. Vac. (Sat'n. Temp. 56.3° F.)			Abs. Pressure 4.5 lb./in.² Gauge Pressure 20.76 in. Vac. (Sat'n. Temp. 61.2° F.)			Abs. Pressure 5.0 lb./in.² Gauge Pressure 19.74 in. Vac. (Sat'n. Temp. 65.7° F.)			Abs. Pressure 5.5 lb./in.² Gauge Pressure 18.73 in. Vac. (Sat'n. Temp. 69.8° F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(At sat'n.)	(7.297)	(87.03)	(0.1727)	(6.542)	(87.74)	(0.1728)	(5.930)	(88.41)	(0.1730)	(5 426)	(89.01)	(0.1731)
60	7.351	87.58	0.1738	.....	.....	.....	.....	.....	.....	.....	.....	.....
70	7.497	89.10	.1767	6.657	89.08	0.1754	5.979	89.06	0.1742	5.428	89.04	0.1732
80	7.642	90.62	.1795	6.786	90.60	.1782	6.096	90.58	.1771	5.533	90.56	.1761
90	7.787	92.15	.1823	6.915	92.13	.1810	6.213	92.12	.1799	5.638	92.10	.1789
100	7.932	93.70	0.1851	7.044	93.68	0.1838	6.329	93.67	0.1827	5.743	93.64	0.1817
110	8.077	95.26	.1879	7.173	95.24	.1866	6.445	95.22	.1855	5.849	95.20	.1844
120	8.222	96.83	.1906	7.302	96.81	.1893	6.562	96.79	.1882	5.955	96.77	.1872
130	8.367	98.42	.1933	7.431	98.40	.1920	6.678	98.38	.1909	6.061	98.36	.1899
140	8.522	100.01	.1960	7.560	99.99	.1947	6.795	99.98	.1936	6.168	99.96	.1925
150	8.667	101.62	0.1986	7.689	101.60	0.1974	6.912	101.58	0.1962	6.274	101.57	0.1952
160	8.812	103.23	.2013	7.818	103.22	.2000	7.029	103.20	.1989	6.380	103.19	.1978
170	8.957	104.86	.2039	7.947	104.85	.2026	7.146	104.83	.2015	6.485	104.82	.2004
180	9.102	106.51	.2065	8.076	106.49	.2052	7.263	106.48	.2041	6.589	106.47	.2030
190	9.247	108.16	.2091	8.205	108.14	.2078	7.380	108.13	.2066	6.795	108.12	.2056
200	9.387	109.82	0.2116	8.334	109.81	0.2103	7.497	109.80	0.2092	6.801	109.78	0.2081
210	9.532	111.50	.2141	8.463	111.49	.2128	7.614	111.48	.2117	6.907	111.46	.2107
220	9.677	113.19	.2166	8.592	113.18	.2153	7.731	113.16	.2142	7.013	113.15	.2132
230	9.822	114.88	.2191	8.721	114.88	.2178	7.848	114.86	.2167	7.120	114.84	.2157
240	9.967	116.59	.2216	8.850	116.59	.2203	7.965	116.57	.2192	7.226	116.55	.2181
250	10.11	118.31	0.2240	8.979	118.31	0.2228	8.082	118.29	0.2216	7.332	118.27	0.2206
260	10.25	120.04	.2264	9.108	120.03	.2252	8.199	120.02	.2240	7.438	120.00	.2230
270	10.40	121.78	.2288	9.237	121.77	.2276	8.316	121.76	.2264	7.544	121.74	.2254
280	10.54	123.53	.2312	9.366	123.52	.2300	8.422	123.51	.2288	7.651	123.49	.2278
290	10.69	125.30	.2336	9.495	125.29	.2323	8.538	125.28	.2312	7.758	125.26	.2302
300	10.83	127.09	0.2359	9.624	127.08	0.2347	8.654	127.07	0.2336	7.864	127.05	0.2325
310	10.97	128.88	.2383	9.753	128.88	.2370	8.771	128.86	.2359	7.970	128.85	.2349
320	11.12	130.68	.2406	9.882	130.68	.2394	8.887	130.67	.2383	8.077	130.65	.2372
330	11.26	132.50	.2429	10.01	132.49	.2417	9.003	132.48	.2406	8.182	132.47	.2395
340	11.40	134.32	.2452	10.14	134.32	.2440	9.120	134.31	.2429	8.287	134.29	.2418
350	11.54	136.16	0.2475	10.27	136.16	0.2463	9.236	136.14	0.2451	8.392	136.13	0.2441
360	11.69	138.01	0.2498	10.39	138.01	.2485	9.352	137.99	.2474	8.497	137.98	.2464
370	.....	.....	.....	10.52	139.86	0.2508	9.468	139.85	0.2497	8.602	139.84	0.2486

Temp. ° F.	Abs. Pressure 6.0 lb./in.² Gauge Pressure 17.71 in. Vac. (Sat'n. Temp. 73.7° F.)			Abs. Pressure 6.5 lb./in.² Gauge Pressure 16.69 in. Vac. (Sat'n. Temp. 77.3° F.)			Abs. Pressure 7.0 lb./in.² Gauge Pressure 15.67 in. Vac. (Sat'n. Temp. 80.6° F.)			Abs. Pressure 7.5 lb./in.² Gauge Pressure 14.65 in. Vac. (Sat'n. Temp. 83.8° F.)		
(At. sat'n.)	(5.004)	(89.58)	(0.1733)	(4.646)	(90.10)	(0.1735)	(4.336)	(90.60)	(0.1736)	(4.064)	(91.06)	(0.1738)
80	5.066	90.54	0.1751	4.671	90.52	0.1743	.....	.....	.....	.....	.....	.....
90	5.163	92.08	.1779	4.762	92.06	.1771	4.414	92.05	0.1763	4.111	92.03	0.1755
100	5.260	93.62	0.1807	4.853	93.60	0.1799	4.498	93.60	0.1791	4.190	93.58	0.1783
110	5.357	95.18	.1835	4.944	95.16	.1827	4.581	95.16	.1818	4.269	95.14	.1811
120	5.454	96.76	.1862	5.035	96.74	.1854	4.666	96.73	.1845	4.348	96.71	.1838
130	5.551	98.35	.1889	5.125	98.33	.1881	4.749	98.32	.1872	4.427	98.30	.1865
140	5.649	99.95	.1916	5.215	99.93	.1908	4.834	99.91	.1899	4.507	99.90	.1892
150	5.746	101.56	0.1943	5.305	101.54	0.1934	4.919	101.52	0.1926	4.585	101.50	0.1919
160	5.843	103.17	.1969	5.394	103.16	.1961	5.003	103.14	.1952	4.663	103.12	.1945
170	5.940	104.80	.1995	5.484	104.79	.1987	5.086	104.77	.1978	4.741	104.75	.1971
180	6.037	106.45	.2021	5.573	106.43	.2013	5.169	106.42	.2004	4.819	106.40	.1997
190	6.134	108.10	.2047	5.663	108.09	.2038	5.253	108.07	.2030	4.897	108.05	.2023
200	6.233	109.77	0.2072	5.752	109.75	0.2064	5.337	109.73	0.2056	4.975	109.72	0.2048
210	6.330	111.44	.2097	5.841	111.43	.2089	5.420	111.41	.2081	5.053	111.39	.2073
220	6.427	113.13	.2122	5.930	113.11	.2114	5.504	113.10	.2106	5.131	113.08	.2098
230	6.525	114.83	.2147	6.021	114.81	.2139	5.587	114.80	.2131	5.209	114.78	.2123
240	6.622	116.54	.2172	6.110	116.52	.2164	5.671	116.50	.2156	5.286	116.49	.2148
250	6.719	118.26	0.2197	6.200	118.24	0.2188	5.755	118.22	0.2180	5.365	118.21	0.2173
260	6.816	119.99	.2221	6.290	119.97	.2212	5.838	119.95	.2204	5.444	119.94	.2197
270	6.913	121.73	.2245	6.381	121.71	.2236	5.921	121.69	.2228	5.523	121.68	.2221
280	7.011	123.48	.2269	6.470	123.46	.2260	6.004	123.45	.2252	5.602	123.44	.2245
290	7.108	125.25	.2293	6.558	125.23	.2284	6.087	125.22	.2276	5.680	125.21	.2269
300	7.205	127.04	0.2316	6.647	127.02	0.2308	6.170	127.01	0.2300	5.757	127.00	0.2292
310	7.302	128.84	.2340	6.737	128.82	.2331	6.254	128.81	.2323	5.834	128.80	.2316
320	7.398	130.64	.2363	6.827	130.63	.2354	6.337	130.61	.2346	5.911	130.60	.2339
330	7.495	132.46	.2386	6.917	132.44	.2377	6.420	132.43	.2370	5.988	132.42	.2362
340	7.591	134.28	.2409	7.008	134.27	.2400	6.504	134.26	.2393	6.064	134.24	.2385
350	7.687	136.12	0.2432	7.097	136.11	0.2423	6.587	136.09	0.2415	6.142	136.08	0.2408
360	7.784	137.97	.2455	7.186	137.96	.2446	6.670	137.94	.2438	6.221	137.93	.2431
370	7.880	139.83	.2477	7.274	139.82	.2469	6.752	139.80	.2461	6.299	139.79	.2453
380	7.975	141.70	0.2500	7.362	141.69	0.2491	6.834	141.68	.2483	6.378	141.67	.2476
390	.....	.....	.....	..	..	.....	6.916	143.57	0.2506	6.457	143.56	0.2498

TABLE 2A–19. PROPERTIES OF SUPERHEATED VAPOR, FREON 113 (*Continued*)

Temp. °F.	Abs. Pressure 8 0 lb./in.² Gauge Pressure 13 64 in. Vac. (Sat'n. Temp. 86 9° F.)			Abs. Pressure 9 0 lb./in.² Gauge Pressure 11 60 in. Vac. (Sat'n. Temp 92 5° F)			Abs Pressure 10 0 lb /in.² Gauge Pressure 9.57 in. Vac. (Sat'n Temp. 97.6° F.)			Abs. Pressure 11 lb./in.² Gauge Pressure 7.53 in. Vac. (Sat'n. Temp. 102.4° F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(At sat'n.)	(3.828)	(91.32)	(0.1739)	(3 431)	(92.35)	(0 1742)	(3 110)	(93 11)	(0 1745)	(2 845)	(93 81)	(0.1747)
90	3.850	92.01	0.1748	.....	.....	.....	.....	.....	.....	.....	.....	.....
100	3.924	93.56	0.1776	3.481	93.52	0.1763	3.124	93.48	0.1751	.....	.....	.....
110	3.999	95.12	.1804	3.547	95.08	.1791	3.183	95.04	.1779	2.887	95.01	0.1769
120	4.073	96.69	.1831	3.613	96.66	.1819	3.242	96.62	.1806	2.941	96.58	.1796
130	4.147	98.28	.1858	3.679	98.25	.1846	3.301	98.21	.1834	3.995	98.17	.1823
140	4.221	99.88	.1885	3.745	99.84	.1872	3.361	99.81	.1860	3.049	99.77	.1850
150	4.295	101.48	0.1912	3.810	101.45	0.1899	3.420	101.41	0.1887	3.103	101.38	0.1877
160	4.369	103.10	.1938	3.874	103.07	.1925	3.480	103.03	.1914	3.157	103.00	.1903
170	4.442	104.74	.1964	3.940	104.70	.1951	3.539	104.66	.1940	3.211	104.63	.1929
180	4.515	106.38	.1990	4.004	106.34	.1977	3.599	106.31	.1966	3.265	106.28	.1955
190	4.588	108.04	.2016	4.070	108.00	.2003	3.658	107.96	.1991	3.319	107.93	.1981
200	4.661	109.71	0.2041	4.135	109.67	0.2028	3.716	109.63	0.2017	3.373	109.60	0.2006
210	4.734	111.38	.2066	4.199	111.35	.2054	3.774	111.32	.2042	3.426	111.28	.2032
220	4.807	113.07	.2091	4.265	113.04	.2079	3.832	113.01	.2067	3.480	112.97	.2057
230	4.880	114.77	.2116	4.330	114.74	.2104	3.891	114.71	.2092	3.533	114.67	.2082
240	4.952	116.48	.2141	4.395	116.45	.2129	3.950	116.42	.2117	3.586	116.38	.2106
250	5.024	118.20	0.2166	4.460	118.17	0.2153	4.010	118.14	0.2141	3.639	118.10	0.2131
260	5.096	119.93	.2190	4.525	119.91	.2177	4.068	119.87	.2166	3.692	119.84	.2155
270	5.168	121.67	.2214	4.590	121.64	.2201	4.126	121.61	.2190	3.745	121.58	.2179
280	5.240	123.42	.2238	4.656	123.40	.2225	4.185	123.37	.2214	3.798	123.34	.2203
290	5.313	125.19	.2261	4.721	125.17	.2249	4.243	125.15	.2237	3.852	125.12	.2227
300	5.387	126.98	0.2285	4.787	126.96	0.2273	4.302	126.94	0.2261	3.906	126.91	0.2250
310	5.460	128.78	.2309	4.852	128.76	.2296	4.360	128.74	.2285	3.960	128.71	.2274
320	5.533	130.58	.2332	4.918	130.57	.2319	4.419	130.54	.2308	4.014	130.51	.2298
330	5.607	132.40	.2355	4.983	132.39	.2343	4.477	132.36	.2331	4.068	132.33	.2321
340	5.682	134.23	.2378	5.048	134.21	.2366	4.537	134.19	.2354	4.122	134.16	.2344
350	5.756	136.07	0.2401	5.112	136.05	0.2388	4.596	136.03	0.2377	4.175	136.00	0.2367
360	5.830	137.92	.2424	5.178	137.90	.2411	4.656	137.88	.2400	4.229	137.85	.2389
370	5.904	139.78	.2447	5.243	139.76	.2434	4.714	139.74	.2422	4.283	139.71	.2412
380	5.975	141 66	.2470	5.307	141.64	.2456	4.772	141.62	.2445	4.336	141.59	.2434
390	6.047	143.55	0.2492	5.372	143.52	.2479	4.829	143.50	.2467	4.389	143.48	.2457
400	.....	.....	.....	5.436	145.41	0.2501	4.887	145.39	0.2489	4.441	145.37	0.2479
410	.....	.....	.....	.....	.....	.....	.....	.....	.....	4.493	147.28	0.2501

Temp. °F.	Abs. Pressure 12 lb./in.^{2} Gauge Pressure 5 50 in Vac. (Sat'n Temp. 106 8° F)			Abs Pressure 13 lb /in ^{2} Gauge Pressure 3 46 in Vac. (Sat'n. Temp 111 0° F)			Abs. Pressure 14 lb /in ^{2} Gauge Pressure 1 42 in Vac. (Sat'n. Temp. 114 9° F)			Abs. Pressure 16 lb /in.^{2} Gauge Pressure 1 3 lb./in.^{2} (Sat'n Temp.122.1° F)		
(At sat'n)	(2.624)	(94.46)	(0 1750)	(2 435)	(95 08)	(0.1753)	(2 271)	(95 66)	(0 1755)	(2 004)	(96.72)	(0.1760)
110	2.640	94.97	0.1759	.....	.....	.....	.....	.....	.....	.....	.....	.....
120	2.689	96.55	.1786	2.477	96.51	0.1778	2.291	96.47	0.1770	.....	.....	.....
130	2.738	98.14	.1813	2.522	98.10	.1805	2.334	98.06	.1797	2.034	97.99	0.1782
140	2.788	99.73	.1840	2.567	99.70	.1832	2.377	99.66	.1823	2.072	99.59	.1809
150	2.838	101.34	0.1867	2.613	101.31	0.1858	2.421	101.27	0.1850	2.110	101.20	0.1835
160	2.888	102.97	.1894	2.659	102.94	.1885	2.465	102.90	.1876	2.148	102.83	.1862
170	2.938	104.60	.1920	2.704	104.57	.1911	2.508	104.53	.1902	2.186	104.46	.1888
180	2.987	106.25	.1946	2.749	106.21	.1937	2.550	106.18	.1928	2.224	106.11	.1914
190	3.037	107.90	.1972	2.795	107.87	.1963	2.593	107.84	.1954	2.262	107.77	.1940
200	3.086	109.57	0.1997	2.841	109.54	0.1988	2.635	109.51	0.1980	2.299	109.44	0.1965
210	3.135	111.26	.2022	2.887	111.23	.2013	2.678	111.20	.2005	2.336	111.13	.1991
220	3.184	112.95	.2047	2.933	112.92	.2039	2.720	112.89	.2030	2.374	112.83	.2016
230	3.234	114.65	.2072	2.979	114.62	.2064	2.763	114.59	.2055	2.411	114.53	.2041
240	3.283	116.36	.2097	3.025	116.33	.2088	2.806	116.30	.2080	2.448	116.24	.2065
250	3.332	118.08	0.2121	3.071	118.05	0.2113	2.848	118.02	0.2105	2.486	117.96	0.2090
260	3.382	119.81	.2146	3.117	119.79	.2137	2.890	119.76	.2129	2.523	119.70	.2114
270	4.431	121.55	.2170	3.162	121.53	.2162	2.932	121.50	.2153	2.560	121.45	.2138
280	3.479	123.31	.2194	3.208	123.29	.2186	2.975	123.26	.2177	2.596	123.21	.2162
290	3.528	125.09	.2218	3.254	125.07	.2209	3.018	125.04	.2201	2.633	124.99	.2186
300	3.578	126.88	0.2241	3.300	126.86	0.2232	3.060	126.84	0.2225	2.671	126.78	0.2210
310	3.627	128.68	.2265	3.345	128.66	.2256	3.103	128.64	.2248	2.709	128.58	.2233
320	3.676	130.49	.2288	3 391	130.47	.2279	3.145	130.44	.2271	2.746	130.39	.2257
330	3.725	132.31	.2311	3.436	132.29	.2302	3.187	132.26	.2294	2.783	132.21	.2280
340	3.774	134.14	.2334	3.481	134.12	.2325	3.229	134.09	.2317	2.820	134.04	.2303
350	3.823	135.98	0.2357	3.526	135.96	0.2348	3.271	135.94	0.2340	2.857	135.88	0.2326
360	3.872	137.83	.2380	3.572	137.81	.2371	3.313	137.79	.2363	2.895	137.74	.2349
370	3.922	139.69	.2402	3.617	139.68	.2394	3.355	139.65	.2386	2.932	139.60	.2371
380	3.972	141.57	.2425	3.662	141.56	.2416	3.397	141.52	.2408	2.968	141.47	.2394
390	4.021	143.45	.2447	3.707	143.44	.2439	3.439	143.41	.2430	3.005	143.36	.2416
400	4.069	145.34	0.2469	3.752	145.33	0.2461	3.481	145.31	0.2453	3.042	145.26	0.2438
410	4.117	147.25	0.2491	3.797	147.24	.2483	3.522	147.22	.2475	3.079	147.17	.2460
420	.....	.....	.....	3.841	149.16	0.2505	3.562	149.14	0.2497	3.115	149.10	.2482
430	.....	.....	.....	.....	.....	.....	.....	.....	.....	3.152	151.03	0.2504

TABLE 2A-19. PROPERTIES OF SUPERHEATED VAPOR, FREON 113 (*Continued*)

Temp. °F.	Abs. Pressure 18 lb./in.^{2} Gauge Pressure 3.3 lb./in.^{2} (Sat'n. Temp. 128.6° F.)			Abs. Pressure 20 lb./in.^{2} Gauge Pressure 5.3 lb./in.^{2} (Sat'n. Temp. 134.6° F.)			Abs. Pressure 25 lb./in.^{2} Gauge Pressure 10.3 lb./in.^{2} (Sat'n. Temp. 147.8° F.)			Abs. Pressure 30 lb./in.^{2} Gauge Pressure 15.3 lb./in.^{2} (Sat'n. Temp. 159.1° F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(At sat'n.)	(1.795)	(97.68)	(0.1764)	(1.625)	(98.56)	(0.1769)	(1.317)	(100.50)	(0.1778)	(1.109)	(102.15)	(0.1787)
130	1.799	97.91	0.1769	.....	.....	.....	.....	.....	.....	.....	.....	.....
140	1.833	99.51	.1795	1.640	99.43	0.1783	.....	.....	.....	.....	.....	.....
150	1.867	101.12	0.1822	1.672	101.05	0.1810	1.322	100.87	0.1784	.....	.....	.....
160	1.901	102.75	.1848	1.703	102.68	.1836	1.348	102.50	.1811	1.111	102.31	0.1790
170	1.935	104.39	.1875	1.734	104.32	.1862	1.373	104.14	.1837	1.132	103.96	.1816
180	1.968	106.04	.1901	1.765	105.97	.1888	1.398	105.80	.1863	1.153	105.62	.1842
190	2.002	107.71	.1926	1.796	107.64	.1914	1.423	107.47	.1889	1.173	107.29	.1868
200	2.036	109.39	0.1952	1.827	109.32	0.1940	1.448	109.15	0.1915	1.194	108.97	0.1894
210	2.069	111.08	.1977	1.857	111.01	.1966	1.472	110.84	.1940	1.215	110.67	.1919
220	2.103	112.77	.2003	1.887	112.70	.1991	1.497	112.54	.1966	1.236	112.37	.1945
230	2.136	114.47	.2028	1.917	114.40	.2016	1.522	114.25	.1991	1.257	114.08	.1970
240	2.169	116.18	.2052	1.947	116.12	.2041	1.546	115.96	.2015	1.278	115.80	.1995
250	2.203	117.90	0.2077	1.977	117.84	0.2065	1.571	117.69	0.2040	1.299	117.53	0.2019
260	2.236	119.64	.2101	2.007	119.58	.2090	1.595	119.44	.2064	1.320	119.28	.2044
270	2.269	121.39	.2125	2.037	121.33	.2114	1.619	121.19	.2089	1.341	121.03	.2068
280	2.303	123.15	.2149	2.068	123.09	.2138	1.643	122.95	.2113	1.362	122.80	.2092
290	2.336	124.92	.2173	2.098	124.87	.2162	1.667	124.73	.2137	1.382	124.59	.2116
300	2.370	126.72	0.2197	2.128	126.67	0.2185	1.691	126.53	0.2160	1.402	126.39	0.2140
310	2.403	128.53	.2220	2.158	128.47	.2209	1.716	128.34	.2184	1.422	128.20	.2163
320	2.436	130.34	.2244	2.187	130.28	.2232	1.741	130.16	.2207	1.442	130.02	.2187
330	2.469	132.16	.2267	2.217	132.10	.2255	1.765	131.98	.2231	1.462	131.85	.2210
340	2.502	133.99	.2290	2.247	133.94	.2278	1.789	133.82	.2254	1.483	133.69	.2233
350	2.535	135.83	0.2313	2.277	135.78	0.2301	1.813	135.66	0.2277	1.503	135.54	0.2256
360	2.569	137.69	.2336	2.308	137.64	.2324	1.838	137.52	.2300	1.524	137.40	.2279
370	2.602	139.55	.2358	2.338	139.50	.2347	1.862	139.39	.2322	1.545	139.27	.2302
380	2.635	141.43	.2381	2.368	141.38	.2369	1.886	141.26	.2345	1.565	141.15	.2324
390	2.667	143.32	.2403	2.398	143.27	.2392	1.910	143.15	.2367	1.585	143.05	.2347
400	2.700	145.22	0.2425	2.427	145.17	0.2414	1.933	145.05	0.2389	1.604	144.95	0.2369
410	2.733	147.13	.2447	2.456	147.08	.2436	1.957	146.97	.2411	1.624	146.86	.2391
420	2.765	149.05	.2469	2.485	149.01	.2458	1.981	148.90	.2433	1.645	148.79	.2413
430	2.797	150.99	0.2491	2.515	150.94	.2480	2.005	150.83	.2455	1.665	150.73	.2435
440	.....	.....	.....	2.544	152.89	0.2501	2.029	152.78	.2477	1.685	152.68	.2457
450	.....	.....	.....	.....	.....	.....	2.052	154.74	0.2498	1.706	154.65	0.2479
460	.....	.....	.....	.....	.....	.....	.....	.....	.....	1.726	156.62	0.2500

Temp. °F.	Abs. Pressure 35 lb./in.² Gauge Pressure 20.3 lb./in.² (Sat'n Temp. 169.0° F.)			Abs. Pressure 40 lb./in.² Gauge Pressure 25.3 lb./in.² (Sat'n. Temp. 177.9° F.)			Abs. Pressure 50 lb./in.² Gauge Pressure 35.3 lb./in.² (Sat'n Temp 193.5° F.)			Abs. Pressure 60 lb./in.² Gauge Pressure 45.3 lb./in.² (Sat'n Temp 206.9° F.)		
(At sat'n)	(0.9580)	(105.60)	(0.1795)	(0.8435)	(104.90)	(0.1802)	(0.6809)	(107.14)	(0.1816)	(0.5705)	(109.06)	(0.1827)
170	0.9594	103.77	0.1797	.....	.....	.....	....	.....	.....	.....	.....	.....
180	0.9780	105.43	.1824	0.8462	105.26	0.1808	....	.....	.....	.....	.....	.....
190	0.9963	107.10	.1850	.8627	106.94	.1834	....	.....	.....	.....	.....	.....
200	1.015	108.79	0.1876	0.8791	108.62	0.1860	0.6899	108.27	0.1833	.....	.....	.....
210	1.033	110.49	.1901	.8953	110.32	.1885	.7031	109.97	.1858	0.5738	109.60	0.1835
220	1.051	112.20	.1927	.9114	112.03	.1911	.7163	111.69	.1884	.5853	111.31	.1861
230	1.069	113.91	.1952	.9274	113.74	.1936	.7296	113.41	.1909	.5968	113.04	.1886
240	1.088	115.63	.1977	.9435	115.47	.1961	.7430	115.14	.1934	.6082	114.78	.1912
250	1.106	117.37	0.2002	0.9596	117.21	0.1986	0.7562	116.90	0.1959	0.6193	116.54	0.1937
260	1.124	119.12	.2026	.9756	118.97	.2010	.7693	118.67	.1984	.6303	118.32	.1961
270	1.142	120.88	.2051	0.9915	120.74	.2035	.7821	120.45	.2008	.6413	120.11	.1986
280	1.160	122.66	.2075	1.008	122.52	.2059	.7950	122.23	.2033	.6525	121.91	.2010
290	1.177	124.45	.2099	1.023	124.31	.2083	.8079	124.03	.2057	.6639	123.72	.2035
300	1.195	126.26	0.2122	1.038	126.12	0.2107	0.8207	125.84	0.2081	0.6751	125.53	0.2059
310	1.212	128.07	.2146	1.054	127.94	.2131	.8335	127.66	.2104	.6860	127.36	.2083
320	1.230	129.89	.2169	1.070	129.76	.2154	.8463	129.48	.2128	.6969	129.19	.2106
330	1.248	131.72	.2193	1.085	131.59	.2178	.8591	131.31	.2152	.7079	131.03	.2130
340	1.266	133.56	.2216	1.101	133.44	.2201	.8716	133.16	.2175	.7188	132.89	.2153
350	1.284	135.41	0.2239	1.117	135.29	0.2224	0.8844	135.02	0.2198	0.7296	134.75	0.2176
360	1.302	137.27	.2262	1.133	137.16	.2247	.8973	136.89	.2221	.7403	136.63	.2199
370	1.319	139.15	.2285	1.148	139.03	.2269	.9101	138.77	.2244	.7510	138.52	.2222
380	1.336	141.03	.2307	1.164	140.91	.2292	.9228	140.67	.2266	.7619	140.42	.2245
390	1.353	142.93	.2329	1.179	142.81	.2314	.9354	142.57	.2289	.7725	142.33	.2267
400	1.370	144.83	0.2352	1.194	144.72	0.2337	0.9480	144.48	0.2311	0.7831	144.24	0.2290
410	1.388	146.75	.2374	1.210	146.64	.2359	.9605	146.41	.2333	.7937	146.16	.2312
420	1.405	148.68	.2396	1.225	148.57	.2381	.9728	148.35	.2356	.8043	148.10	.2334
430	1.422	150.62	.2418	1.240	150.51	.2403	.9851	150.30	.2378	.8151	150.06	.2356
440	1.439	152.58	.2440	1.256	152.47	.2425	0.9974	152.25	.2400	.8257	152.02	.2378
450	1.457	154.54	0.2461	1.271	154.44	0.2447	1.010	154.22	0.2421	0.8362	154.00	0.2400
460	1.474	156.52	.2483	1.286	156.41	.2468	1.023	156.21	.2443	.8466	155.98	.2422
470	1.491	158.51	0.2505	1.302	158.40	.2490	1.036	158.20	.2464	.8570	157.98	.2443
480	....	.....	.....	1.317	160.40	0.2511	1.048	160.20	.2486	.8675	159.98	.2465
490	....	.....	.....	....	.....	.....	1.060	162.22	.2507	.8776	162.00	.2486
500	....	.....	.....	....	.....	.....	1.072	164.24	0.2528	0.8880	164.03	0.2508
510	....	.....	.....	....	.....	.....	.....	.....	.....	0.8987	166.07	0.2529

TABLE 2A-19. PROPERTIES OF SUPERHEATED VAPOR, FREON 113 (*Continued*)

Temp. ° F.	Abs. Pressure 70 lb /in.² Gauge Pressure 55.3 lb./in.² (Sat'n. Temp 218.8° F.)		
t	V	H	S
(At sat'n.)	(0.4900)	(110.75)	(0.1838)
220	0.4911	110.96	0.1841
230	.5013	112.68	.1866
240	.5116	114.43	.1892
250	0.5217	116.20	0.1917
260	.5315	117.99	.1942
270	.5413	119.79	.1967
280	.5511	121.60	.1991
290	.5610	123.41	.2016
300	0.5709	125.24	0.2040
310	.5808	127.07	.2064
320	.5907	128.91	.2087
330	.6005	130.76	.2111
340	.6099	132.62	.2134
350	0.6191	134.49	0.2158
360	.6283	136.37	.2181
370	.6375	138.26	.2204
380	.6469	140.16	.2226
390	.6562	142.08	.2249
400	0.6655	144.00	0.2271
410	.6748	145.93	.2294
420	.6842	147.88	.2316
430	.6936	149.84	.2338
440	.7029	151.80	.2360
450	0.7122	153.78	0.2382
460	.7215	155.77	.2404
470	.7305	157.77	.2426
480	.7396	159.78	.2447
490	.7478	161.80	.2468
500	0.7571	163.83	0.2490
510	.7664	165.88	.2511
520	0.7757	167.93	0.2582

DICHLOROTETRAFLUOROETHANE, FREON 114

TABLE 2A.-20. PROPERTIES OF LIQUID AND SATURATED VAPOR

Temp. °F. t	Pressure		Volume		Density		Enthalpy from −40°F.			Entropy from −40°F.		Temp. °F. t
	Absolute lbs./in.^{2} p	Gage lbs./in.^{2} $g.p.$	Liquid ft.^{3}/lb. v_f	Vapor ft.^{3}/lb. v_g	Liquid lbs./ft.^{3} $1/v_f$	Vapor lbs./ft.^{3} $1/v_g$	Liquid Btu./lb. h_f	Latent Btu./lb. h_{fg}	Vapor Btu./lb. h_g	Liquid Btu./lb.°F. s_f	Vapor Btu./lb.°F. s_g	
−40	1.866	26.12*	0.00978	14.02	102.25	0.07132	0.00	65.91	65.91	0.0000	0.1571	−40
−38	1.990	25.87*	.00980	13.20	102.08	.07574	0.45	65.74	66.19	.0011	.1570	−38
−36	2.121	25.60*	.00981	12.44	101.90	.08038	0.91	65.56	66.47	.0021	.1569	−36
−34	2.259	25.32*	.00983	11.73	101.72	.08524	1.36	65.38	66.74	.0032	.1568	−34
−32	2.404	25.03*	.00985	11.07	101.55	.09034	1.81	65.21	67.02	.0042	.1567	−32
−30	2.557	24.72*	0.00987	10.45	101.37	0.09568	2.27	65.03	67.30	0.0053	0.1567	−30
−28	2.718	24.39*	.00988	9.877	101.19	.1013	2.72	64.86	67.58	.0063	.1567	−28
−26	2.887	24.04*	.00990	9.338	101.01	.1071	3.17	64.68	67.86	.0074	.1566	−26
−24	3.064	23.68*	.00992	8.833	100.83	.1132	3.63	64.51	68.14	.0084	.1565	−24
−22	3.249	23.31*	.00994	8.362	100.65	.1196	4.08	64.34	68.42	.0095	.1565	−22
−20	3.444	22.91*	0.00995	7.921	100.47	0.1263	4.54	64.16	68.70	0.0105	0.1565	−20
−18	3.648	22.49*	.00997	7.508	100.29	.1332	4.99	63.99	68.98	.0116	.1565	−18
−16	3.862	22.06*	.00999	7.121	100.11	.1404	5.44	63.81	69.26	.0126	.1564	−16
−14	4.085	21.61*	.01001	6.757	99.92	.1480	5.90	63.64	69.54	.0136	.1564	−14
−12	4.319	21.13*	.01003	6.416	99.74	.1559	6.35	63.46	69.82	.0146	.1564	−12
−10	4.564	20.63*	0.01005	6.095	99.56	0.1641	6.81	63.29	70.10	0.0157	0.1564	−10
− 8	4.819	20.11*	.01006	5.794	99.37	.1726	7.26	63.11	70.38	.0167	.1564	− 8
− 6	5.086	19.57*	.01008	5.510	99.19	.1815	7.72	62.94	70.66	.0177	.1564	− 6
− 4	5.365	19.00*	.01010	5.244	99.00	.1907	8.18	62.77	70.94	.0187	.1564	− 4
− 2	5.655	18.41*	.01012	4.992	98.81	.2003	8.63	62.59	71.22	.0197	.1565	− 2

0	5.958	17.79*	0.01014	4.756	98.62	0.2103	9.09	62.42	71.50	0.0207	0.1565	0
2	6.274	17.15*	.01016	4.533	98.44	.2206	9.54	62.24	71.78	.0217	.1565	2
4	6.603	16.48*	.01018	4.322	98.25	.2314	10.00	62.07	72.07	.0227	.1565	4
5†	6.772	16.14*	.01019	4.221	98.15	.2369	10.23	61.98	72.21	.0232	.1565	5†
6	6.945	15.78*	.01020	4.123	98 06	.2425	10.46	61.89	72 35	.0236	.1566	6
8	7.301	15.06*	.01022	3.935	97.87	.2541	10.91	61.71	72.63	.0246	.1566	8
10	7.671	14.31*	0.01024	3.758	97.68	0.2661	11.37	61.54	72.91	0.0256	0.1566	10
12	8.057	13.52*	.01026	3.591	97.48	.2785	11.83	61.36	73.19	.0266	.1567	12
14	8.457	12.71*	.01028	3.432	97.29	.2914	12.29	61.19	73.47	.0275	.1567	14
16	8.873	11.86*	.01030	3 282	97.10	.3047	12.75	61.01	73.75	.0285	.1568	16
18	9.305	10.98*	.01032	3.140	96.90	.3185	13.20	60.83	74.04	.0295	.1568	18
20	9.753	10.07*	0.01034	3.005	96.71	0.3328	13.66	60.65	74.32	0.0304	0.1569	20
22	10.22	9.12*	.01036	2.877	96.51	.3476	14.12	60.48	74.60	.0314	.1569	22
24	10.70	8.14*	.01038	2.756	96.32	.3629	14 58	60.30	74.88	.0323	.1570	24
26	11.20	7.12*	.01040	2.641	96.12	.3786	15.05	60.12	75.17	.0333	.1571	26
28	11.72	6.07*	.01043	2.532	95.92	.3949	15.51	59.94	75.45	.0342	.1571	28
30	12.25	4.99*	0.01045	2.429	95.73	0.4118	15.97	59.76	75.73	0.0352	0.1572	30
32	12.81	3.85*	.01047	2.330	95.53	.4292	16.43	59.58	76.01	.0361	.1573	32
34	13.38	2.69*	.01049	2.236	95.33	.4472	16.89	59.40	76.29	.0370	.1574	34
36	13.98	1.47*	.01051	2.147	95.13	.4658	17.36	59.22	76 58	.0380	.1575	36
38	14.59	0.22*	.01053	2.062	94.93	.4849	17.82	59.04	76.86	.0389	.1575	38
40	15.22	0.52	0.01056	1.982	94.73	0.5047	18.28	58.86	77.14	0.0398	0.1576	40
42	15.88	1.18	.01058	1.905	94 52	.5250	18 75	58.67	77 42	.0408	.1577	42
44	16.56	1.86	.01060	1.832	94.32	5460	19 21	58.49	77 70	.0417	.1578	44
46	17.26	2.56	.01063	1.762	94.12	.5676	19 68	58 31	77.99	.0426	.1579	46
48	17.98	3.28	.01065	1.695	93.91	.5899	20 14	58 12	78 27	.0435	.1580	48

* Inches of mercury below one atmosphere.
† Standard ton temperatures.

TABLE 2A-20. PROPERTIES OF LIQUID AND SATURATED VAPOR, FREON 114 (*Continued*)

Temp. °F. t	Pressure		Volume		Density		Enthalpy from −40°F.			Entropy from −40°F.		Temp. °F. t
	Absolute lbs./in.^{2} p	Gage lbs./in.^{2} $g.p.$	Liquid ft.^{3}/lb. v_f	Vapor ft.^{3}/lb. v_g	Liquid lbs./ft.^{3} $1/v_f$	Vapor lbs./ft.^{3} $1/v_g$	Liquid Btu./lb. h_f	Latent Btu./lb. h_{fg}	Vapor Btu./lb. h_g	Liquid Btu./lb.°F. s_f	Vapor Btu./lb.°F. s_g	
50	18.73	4.03	0.01067	1.632	93.71	0.6129	20.61	57.94	78.55	0.0444	0.1581	50
52	19.50	4.80	.01070	1.571	93.50	.6365	21.08	57.75	78.83	.0453	.1582	52
54	20.29	5.59	.01072	1.513	93.30	.6609	21.54	57.56	79.11	.0463	.1583	54
56	21.11	6.41	.01074	1.458	93.09	.6859	22.01	57.38	79.39	.0472	.1584	56
58	21.96	7.26	.01077	1.405	92.88	.7117	22.48	57.19	79.67	.0481	.1585	58
60	22.83	8.13	0.01079	1.354	92.68	0.7383	22.95	57.00	79.95	0.0490	0.1587	60
62	23.72	9.02	.01082	1.306	92.47	.7655	23.42	56.81	80.23	.0499	.1588	62
64	24.64	9.94	.01084	1.260	92.26	.7936	23.89	56.62	80.51	.0508	.1589	64
66	25.59	10.89	.01086	1.216	92.05	.8225	24.36	56.43	80.79	.0517	.1590	66
68	26.57	11.87	.01089	1.174	91.84	.8521	24.83	56.24	81.07	.0526	.1591	68
70	27.57	12.87	0.01091	1.133	91.63	0.8826	25.30	56.04	81.35	0.0534	0.1593	70
72	28.61	13.91	.01094	1.094	91.41	.9140	25.78	55.85	81.62	.0543	.1594	72
74	29.67	14.97	.01097	1.057	91.20	.9462	26.25	55.65	81.90	.0552	.1595	74
76	30.76	16.06	.01099	1.021	90.99	0.9793	26.73	55.45	82.18	.0561	.1596	76
78	31.88	17.18	.01102	0.9869	90.77	1.013	27.20	55.26	82.46	.0570	.1597	78
80	33.04	18.34	0.01104	0.9541	90.56	1.048	27.68	55.06	82.73	0.0579	0.1599	80
82	34.22	19.52	.01107	.9226	90.34	1.084	28.15	54.86	83.01	.0587	.1600	82
84	35.44	20.74	.01110	.8923	90.13	1.121	28.63	54.66	83.29	.0596	.1601	84
86†	36.69	21.99	.01112	.8632	89.91	1.159	29.11	54.46	83.56	.0605	.1603	86†
88	37.97	23.27	.01115	.8353	89.69	1.197	29.58	54.25	83.84	.0613	.1604	88

90	39.29	24.59	0.01118	0.8084	89.47	1.237	30.06	54.05	84.11	0.0622	0.1605	90
92	40.64	25.94	.01120	.7827	89.25	1.278	30.54	53.84	84.39	.0631	.1607	92
94	42.02	27.32	.01123	.7579	89.03	1.320	31.02	53.64	84.66	.0639	.1608	94
96	43.44	28.74	.01126	.7340	88.81	1.362	31.50	53 43	84.93	.0648	.1609	96
98	44.89	30.19	.01129	.7111	88.59	1.406	31.99	53.22	85.21	.0656	.1611	98
100	46.39	31.69	0.01132	0.6890	88.37	1.452	32.47	53.01	85.48	0.0665	0.1612	100
102	47.92	33.22	.01135	.6677	88.15	1.498	32.95	52.80	85.75	.0674	.1614	102
104	49.48	34.78	.01137	.6472	87.93	1.545	33.43	52.59	86.02	.0682	.1615	104
106	51.09	36.39	.01140	.6274	87.70	1.594	33.92	52.37	86.29	.0691	.1617	106
108	52.73	38.03	.01143	.6084	87.48	1.644	34.40	52.16	86.56	.0699	.1618	108
110	54.41	39.71	0.01146	0.5901	87.25	1.695	34.89	51.94	86.83	0.0708	0.1619	110
112	56.14	41.44	.01149	.5724	87.01	1.747	35.38	51.72	87.09	.0716	.1621	112
114	57.90	43.20	.01152	.5554	86.77	1.801	35.87	51.50	87.36	.0725	.1622	114
116	59.70	45.00	.01156	.5389	86.54	1.856	36.35	51.28	87.63	.0733	.1624	116
118	61.55	46.85	.01159	.5230	86.31	1.912	36.84	51.05	87.89	.0741	.1625	118
120	63.44	48.74	0.01162	0.5077	86.08	1.970	37.33	50.83	88.16	0.0750	0.1627	120
122	65.37	50.67	.01165	.4929	85.85	2 029	37.83	50.60	88.42	.0758	.1628	122
124	67.35	52.65	.01168	.4787	85.61	2.089	38.32	50.37	88.69	.0767	.1630	124
126	69.37	54.67	.01171	.4649	85.37	2.151	38.81	50.14	88.95	.0775	.1631	126
128	71.43	56.73	.01175	.4515	85.13	2.215	39.31	49.91	89.21	.0783	.1633	128
130	73.54	58.84	0.01178	0.4387	84.89	2 280	39.80	49.67	89.47	0.0792	0.1634	130
132	75.69	60.99	.01181	.4262	84.65	2 346	40.30	49.44	89.73	.0800	.1635	132
134	77.90	63.20	.01185	.4142	84.41	2.414	40.80	49.20	89.99	.0808	.1637	134
136	80.15	65.45	.01188	.4025	84.16	2.484	41.29	48.96	90.25	.0816	.1638	136
138	82.44	67.74	.01192	.3912	83.91	2.556	41.79	48.72	90.51	.0825	.1640	138
140	84.79	70.09	0.01195	0.3803	83.66	2.629	42.29	48.47	90.76	0.0833	0.1641	140

† Standard ton temperatures.

TABLE 2A-21. PROPERTIES OF SUPERHEATED VAPOR, FREON 114

Temp. °F.	Abs. Pressure 1.5 lb./in.² Gage Pressure 26.87 in. Vac. (Sat'n. Temp. −46.6° F.)			Abs. Pressure 2.0 lb./in.² Gage Pressure 25.85 in. Vac. (Sat'n. Temp. −37.8° F.)			Abs. Pressure 2.5 lb./in.² Gage Pressure 24.83 in. Vac. (Sat'n. Temp. −30.7° F.			Abs. Pressure 3.0 lb./in.² Gage Pressure 23.81 in. Vac. (Sat'n. Temp. −24.7° F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(At sat'n.)	(17.18)	(65.00)	(0.1575)	(13.14)	(66.21)	(0.1570)	(10.68)	(67.20)	(0.1567)	(9.011)	(68.04)	(0.1565)
−40	17.46	65.93	0.1596	......	......	......	......	......	......	......	......	......
−30	17.89	67.35	.1630	13.39	67.33	0.1596	10.70	67.30	0.1570	......	......	......
−20	18.31	68.78	.1663	13.71	68.76	.1629	10.95	68.74	.1603	9.108	68.72	0.1581
−10	18.73	70.23	.1695	14.03	70.21	.1662	11.20	70.18	.1635	9.320	70.16	.1614
0	19.15	71.69	0.1727	14.34	71.67	0.1694	11.46	71.64	0.1667	9.532	71.62	0.1646
10	19.57	73.16	.1759	14.66	73.14	.1725	11.71	73.12	.1699	9.744	73.10	.1678
20	19.99	74.65	.1790	14.98	74.63	.1757	11.96	74.61	.1731	9.956	74.59	.1709
30	20.42	76.15	.1821	15.29	76.13	.1788	12.22	76.11	.1762	10.17	76.09	.1740
40	20.84	77.66	.1852	15.61	77.65	.1818	12.47	77.63	.1792	10.38	77.61	.1771
50	21.26	79.19	0.1882	15.92	79.18	0.1849	12.73	79.16	0.1823	10.59	79.14	0.1801
60	21.68	80.73	.1912	16.24	80.72	.1879	12.98	80.70	.1853	10.80	80.68	.1831
70	22.10	82.29	.1942	16.56	82.28	.1908	13.23	82.26	.1882	11.01	82.24	.1861
80	22.52	83.86	.1971	16.87	83.85	.1938	13.49	83.83	.1912	11.23	83.81	.1890
90	22.94	85.45	.2000	17.19	85.43	.1967	13.74	85.42	.1941	11.44	85.40	.1919
100	23.36	87.05	0.2029	17.51	87.03	0.1996	13.99	87.02	0.1970	11.65	87.00	0.1948
110	23.78	88.66	.2058	17.82	88.64	.2024	14.25	88.63	.1998	11.86	88.61	.1977
120	24.20	90.29	.2086	18.14	90.27	.2053	14.50	90.26	.2026	12.07	90.24	.2005
130	24.62	91.93	.2114	18.45	91.91	.2081	14.75	91.90	.2054	12.28	91.88	.2033
140	25.04	93.58	.2142	18.77	93.57	.2108	15.00	93.55	.2082	12.49	93.54	.2061
150	25.46	95.25	0.2170	19.08	95.23	0.2136	15.26	95.22	0.2110	12.70	95.21	0.2089
160	25.88	96.93	.2197	19.40	96.91	.2163	15.51	96.90	.2137	12.92	96.89	.2116
170	26.30	98.62	.2224	19.71	98.61	.2190	15.76	98.60	.2164	13.13	98.58	.2143
180	26.72	100.33	.2251	20.03	100.32	.2217	16.01	100.31	.2191	13.34	100.29	.2170
190	27.14	102.06	.2278	20.35	102.04	.2244	16.27	102.03	.2218	13.55	102.02	.2197
200	27.56	103.79	0.2304	20.66	103.78	0.2271	16.52	103.77	0.2245	13.76	103.76	0.2223
210	27.98	105.54	.2331	20.98	105.53	.2297	16.77	105.52	.2271	13.97	105.51	.2250
220	28.40	107.31	.2357	21.29	107.30	.2323	17.02	107.28	.2297	14.18	107.27	.2276
230	28.82	109.09	.2383	21.61	109.08	.2349	17.28	109.06	.2323	14.39	109.05	.2302
240	29.24	110.88	.2409	21.92	110.87	.2375	17.53	110.86	.2349	14.60	110.84	.2328
250	29.66	112.69	0.2434	22.24	112.67	0.2401	17.78	112.66	0.2375	14.81	112.65	0.2353
260	......	......	......	22.55	114.49	0.2426	18.03	114.48	0.2400	15.02	114.47	.2379
270	......	......	......	......	......	......	......	......	......	15.23	116.31	0.2404

Temp. °F.	Abs Pressure 3.5 lb/in.^{2} Gage Pressure 22.80 in. Vac. (Sat'n. Temp. −19.5° F.)			Abs. Pressure 4.0 lb/in.^{2} Gage Pressure 21.78 in. Vac. (Sat'n. Temp. −14.8° F.)			Abs. Pressure 4.5 lb/in.^{2} Gage Pressure 20.76 in. Vac. (Sat'n. Temp. −10.5° F.)			Abs. Pressure 5.0 lb/in.^{2} Gage Pressure 19.74 in. Vac. (Sat'n Temp. −6.6° F.)		
(At sat'n.)	(7.806)	(68.77)	(0.1565)	(6.893)	(69.43)	(0.1565)	(6.177)	(70.02)	(0.1564)	(5.601)	(70.57)	(0.1564)
−10	7.976	70.14	0.1596	6.967	70.12	0.1580	6.183	70.10	0.1566	......	......	......
0	8.158	71.60	0.1628	7.127	71.58	0.1612	6.326	71.56	0.1598	5.684	71.54	0.1585
10	8.340	73.08	.1660	7.287	73.06	.1644	6.468	73.04	.1630	5.813	73.02	.1617
20	8.522	74.57	.1691	7.446	74.55	.1675	6.610	74.53	.1661	5.941	74.51	.1649
30	8.704	76.07	.1722	7.606	76.05	.1706	6.752	76.04	.1692	6.069	76.02	.1680
40	8.886	77.59	.1753	7.765	77.57	.1737	6.894	77.56	.1723	6.197	77.54	.1711
50	9.068	79.12	0.1783	7.925	79.10	0.1767	7,036	79.09	0.1753	6.325	79.07	0.1741
60	9.250	80.67	.1813	8.085	80.65	.1797	7.178	80.63	.1783	6.453	80.61	.1771
70	9.431	82.23	.1843	8.244	82.21	.1827	7.320	82.19	.1813	6.581	82.17	.1801
80	9.613	83.80	.1872	8.403	83.78	.1856	7.462	83.76	.1843	6.709	83.75	.1830
90	9.795	85.38	.1901	8.562	85.37	.1885	7.604	85.35	.1872	6.837	85.33	.1859
100	9.976	86.98	0.1930	8.721	86.97	0.1914	7.745	86.95	0.1901	6.964	86.93	0.1888
110	10.16	88.60	.1959	8.880	88.58	.1943	7.887	88.57	.1929	7.092	88.55	.1917
120	10.34	90.23	.1987	9.039	90.21	.1971	8.028	90.20	.1957	7.219	90.18	.1945
130	10.52	91.87	.2015	9.198	91.85	.1999	8.170	91.84	.1985	7.346	91.82	.1973
140	10.70	93.52	.2043	9.356	93.51	.2027	8.311	93.49	.2013	7.474	93.48	.2001
150	10.88	95.19	0.2071	9.515	95.18	0.2055	8.452	95.16	0.2041	7.601	95.15	0.2029
160	11.06	96.87	.2098	9.673	96.86	.2082	8.593	96.84	.2068	7.728	96.83	.2056
170	11.24	98.57	.2125	9.832	98.56	.2109	8.734	98.54	.2096	7.855	98.53	.2083
180	11.43	100.28	.2152	9.990	100.27	.2136	8.875	100.25	.2123	7.983	100.24	.2110
190	11.61	102.00	.2179	10.15	101.99	.2163	9.015	101.98	.2149	8.110	101.96	.2137
200	11.79	103.74	0.2205	10.31	103.73	0.2190	9.156	103.72	0.2176	8.236	103.70	0.2163
210	11.97	105.49	.2232	10.47	105.48	.2216	9.297	105.47	.2202	8.363	105.46	.2190
220	12.15	107.26	.2258	10.62	107.25	.2242	9.438	107.24	.2228	8.490	107.22	.2216
230	12.33	109.04	.2284	10.78	109.03	.2268	9.579	109.02	.2254	8.617	109.00	.2242
240	12.51	110.83	.2310	10.94	110.82	.2294	9.720	110.81	.2280	8.744	110.80	.2268
250	12.69	112.64	0.2335	11.10	112.63	0.2320	9.861	112.62	0.2306	8.871	112.61	0.2294
260	12.87	114.46	.2361	11.26	114.45	.2345	10.00	114.44	.2331	8.998	114.43	.2319
270	13.05	116.30	.2386	11.42	116.28	.2371	10.14	116.27	.2357	9.125	116.26	.2344
280	13.23	118.15	0.2411	11.57	118.13	0.2396	10.28	118.12	0.2382	9.251	118.11	.2370
290	......	......	......	......	......	......	......	......	......	9.378	119.98	0.2395

TABLE 2A-21. PROPERTIES OF SUPERHEATED VAPOR, FREON 114 (*Continued*)

Temp. °F.	Abs. Pressure 5.5 lb./in.^{2} Gage Pressure 18.73 in. Vac. (Sat'n. Temp. −3.1° F.)			Abs. Pressure 6.0 lb./in.^{2} Gage Pressure 17.71 in. Vac. (Sat'n. Temp. +0.3° F.)			Abs. Pressure 6.5 lb./in.^{2} Gage Pressure 16.60 in. Vac. (Sat'n. Temp. 3.4° F.)			Abs. Pressure 7.0 lb./in.^{2} Gage Pressure 15.67 in. Vac. (Sat'n. Temp. 6.3° F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(At sat'n.)	(5.125)	(71.07)	(0.1564)	(4.726)	(71.54)	(0.1565)	(4.386)	(71.98)	(0.1565)	(4.094)	(72.39)	(0.1566)
0	5.159	71.52	0.1574	......	......	......	......	......	......	......	......	......
10	5.276	73.00	.1606	4.829	72.98	0.1595	4.451	72.96	0.1586	4.127	72.94	0.1577
20	5.393	74.49	.1637	4.937	74.47	.1627	4.551	74.45	.1618	4.220	74.43	.1609
30	5.510	76.00	.1668	5.044	75.98	.1658	4.650	75.96	.1649	4.312	75.94	.1640
40	5.626	77.52	.1699	5.151	77.50	.1689	4.749	77.48	.1679	4.404	77.46	.1671
50	5.743	79.05	0.1730	5.258	79.03	0.1719	4.848	79.01	0.1710	4.496	78.99	0.1701
60	5.860	80.60	.1760	5.365	80.58	.1749	4.947	80.56	.1740	4.588	80.54	.1731
70	5.976	82.16	.1789	5.472	82.14	.1779	5.046	82.12	.1770	4.680	82.10	.1761
80	6.092	83.73	.1819	5.579	83.71	.1809	5.145	83.70	.1799	4.772	83.68	.1790
90	6.209	85.32	.1848	5.686	85.30	.1838	5.244	85.28	.1828	4.864	85.27	.1819
100	6.325	86.92	0.1877	5.793	86.90	0.1867	5.342	86.89	0.1857	4.956	86.87	0.1848
110	6.441	88.53	.1905	5.899	88.52	.1895	5.441	88.50	.1886	5.048	88.49	.1877
120	6.557	90.16	.1934	6.006	90.15	.1924	5.539	90.13	.1914	5.139	90.12	.1905
130	6.673	91.81	.1962	6.112	91.79	.1952	5.638	91.78	.1942	5.231	91.76	.1933
140	6.789	93.46	.1990	6.219	93.45	.1980	5.736	93.43	.1970	5.322	93.42	.1961
150	6.905	95.13	0.2017	6.325	95.12	0.2007	5.834	95.10	0.1998	5.414	95.09	0.1989
160	7.021	96.82	.2045	6.431	96.80	.2035	5.932	96.79	.2025	5.505	96.77	.2016
170	7.136	98.52	.2072	6.537	98.50	.2062	6.031	98.49	.2052	5.596	98.47	.2043
180	7.252	100.23	.2099	6.644	100.21	.2089	6.129	100.20	.2079	5.687	100.18	.2070
190	7.368	101.95	.2126	6.750	101.94	.2115	6.227	101.92	.2106	5.778	101.91	.2097
200	7.483	103.69	0.2152	6.856	103.68	0.2142	6.325	103.66	0.2133	5.870	103.65	0.2124
210	7.599	105.44	.2179	6.962	105.43	.2168	6.423	105.42	.2159	5.961	105.40	.2150
220	7.714	107.21	.2205	7.068	107.20	.2195	6.521	107.19	.2185	6.052	107.17	.2176
230	7.830	108.99	.2231	7.173	108.98	.2221	6.619	108.97	.2211	6.143	108.95	.2202
240	7.945	110.78	.2257	7.279	110.77	.2246	6.716	110.76	.2237	6.234	110.75	.2228
250	8.061	112.59	0.2282	7.385	112.58	0.2272	6.814	112.57	0.2263	6.325	112.56	0.2254
260	8.176	114.42	.2308	7.491	114.40	.2298	6.912	114.39	.2288	6.416	114.38	.2279
270	8.291	116.25	.2333	7.597	116.24	.2323	7.010	116.23	.2314	6.507	116.22	.2305
280	8.407	118.10	.2358	7.703	118.09	.2348	7.108	118.08	.2339	6.597	118.07	.2330
290	8.522	119.96	0.2383	7.809	119.95	.2373	7.205	119.94	.2364	6.688	119.93	.2355
300	......	......	......	7.914	121.83	0.2398	7.303	121.82	0.2389	6.779	121.81	0.2380

Temp. ° F.	Abs Pressure 7.5 lb./in.^{2} Gage Pressure 14.65 in. Vac. (Sat'n. Temp 9.1° F.)			Abs. Pressure 8.0 lb./in.^{2} Gage Pressure 13 64 in Vac. (Sat'n. Temp 11 7° F.)			Abs. Pressure 9 lb./in.^{2} Gage Pressure 11 60 in. Vac. (Sat'n. Temp. 16 6° F.)			Abs. Pressure 10 lb./in.^{2} Gage Pressure 9.57 in. Vac. (Sat'n. Temp. 21.1° F.)		
(At sat'n.)	(3.839)	(72.78)	(0.1566)	(3.615)	(73.15)	(0.1567)	(3.240)	(73.84)	(0.1568)	(2.937)	(74.47)	(0.1569)
10	3.846	72.92	0.1569	......	......	......	......	......	......	......	......	......
20	3.933	74.41	.1600	3.682	74.39	0.1593	3.263	74.35	0.1578	......	......	......
30	4.019	75.92	.1631	3.763	75.90	.1624	3.336	75.86	.1609	2.994	75.82	0.1597
40	4.105	77.44	.1662	3.844	77.42	.1655	3.408	77.38	.1640	3.060	77.35	.1628
50	4.191	78.98	0.1693	3.925	78.96	0.1685	3.480	78.92	0.1671	3.125	78.88	0.1658
60	4.277	80.53	.1723	4.006	80.51	.1715	3.553	80.47	.1701	3.190	80.43	.1688
70	4.363	82.09	.1753	4.086	82.07	.1745	3.625	82.03	.1731	3.255	82.00	.1718
80	4.449	83.66	.1782	4.167	83.64	.1774	3.697	83.61	.1760	3.320	83.58	.1748
90	4.535	85.25	.1811	4.248	85.23	.1803	3.769	85.20	.1789	3.385	85.17	.1777
100	4.621	86.85	0.1840	4.328	86.84	0.1832	3.840	86.80	0.1818	3.450	86.77	0.1806
110	4.707	88.47	.1869	4.409	88.46	.1861	3.912	88.42	.1847	3.515	88.39	.1834
120	4.793	90.10	.1897	4.489	90.09	.1889	3.984	90.05	.1875	3.579	90.02	.1863
130	4.878	91.75	.1925	4.570	91.73	.1917	4.055	91.70	.1903	3.644	91.67	.1891
140	4.964	93.40	.1953	4.650	93.39	.1945	4.127	93.36	.1931	3.708	93.33	.1919
150	5.049	95.07	0.1981	4.730	95.06	0.1973	4.198	95.03	0.1959	3.773	95.00	0.1947
160	5.134	96.76	.2008	4.810	96.75	.2000	4.270	96.72	.1987	3.837	96.69	.1974
170	5.220	98.46	.2035	4.890	98.45	.2028	4.341	98.42	.2014	3.902	98.39	.2001
180	5.305	100.17	.2062	4.970	100.16	.2055	4.412	100.13	.2041	3.966	100.10	.2028
190	5.390	101.90	.2089	5.050	101.88	.2081	4.483	101.86	.2067	4.030	101.83	.2055
200	5.475	103.64	0.2116	5.130	103.62	0.2108	4.555	103.60	0.2094	4.095	103.57	0.2082
210	5.560	105.39	.2142	5.210	105.38	.2134	4.626	105.35	.2121	4.159	105.33	.2108
220	5.645	107.16	.2168	5.290	107.15	.2161	4.697	107.12	.2147	4.223	107.10	.2134
230	5.730	108.94	.2194	5.370	108.93	.2187	4.768	108.91	.2173	4.287	108.88	.2160
240	5.815	110.74	.2220	5.449	110.73	.2213	4.839	110.70	.2199	4.351	110.68	.2186
250	5.900	112.55	0.2246	5.529	112.54	0.2238	4.910	112.51	0.2224	4.415	112.49	0.2212
260	5.985	114.37	.2271	5.609	114.36	.2264	4.981	114.33	.2250	4.479	114.31	.2237
270	6.070	116.21	.2297	5.689	116.19	.2289	5.052	116.17	.2275	4.543	116.15	.2263
280	6.155	118.06	.2322	5.768	118.05	.2314	5.123	118.02	.2300	4.607	118.00	.2288
290	6.240	119.92	.2347	5.848	119.91	.2339	5.194	119.89	.2325	4.671	119.87	.2313
300	6.325	121.80	0.2372	5.927	121.79	0.2364	5.265	121.77	0.2350	4.735	121.75	0.2338
310	......	......	......	6.007	123.68	0.2389	5.336	123.66	0.2375	4.799	123.64	.2363
320	......	......	......	......	......	......	......	......	......	4.862	125.55	0.2387

TABLE 2A-21. PROPERTIES OF SUPERHEATED VAPOR, FREON 114 (*Continued*)

Temp. °F.	Abs. Pressure 11 lb./in.^{2} Gage Pressure 7.53 in. Vac. (Sat'n. Temp. 25.2° F.)			Abs. Pressure 12 lb./in.^{2} Gage Pressure 5.50 in. Vac. (Sat'n. Temp. 29.1° F.)			Abs. Pressure 13 lb./in.^{2} Gage Pressure 3.46 in. Vac. (Sat'n. Temp. 32.7° F.)			Abs. Pressure 14 lb./in.^{2} Gage Pressure 1.42 on. Vac. (Sat'n. Temp. 36.1° F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(At sat'n.)	(2.686)	(75 05)	(0.1570)	(2.477)	(75.60)	(0.1572)	(2.298)	(76.11)	(0.1573)	(2.144)	(76.59)	(0.1575)
30	2.714	75.78	0.1585	2.481	75.74	0.1575	..	..		..		
40	2.774	77.31	.1616	2.536	77.27	.1606	2.335	77.23	0.1596	2.162	77.19	0.1587
50	2.834	78.85	0.1647	2.591	78.81	0.1636	2.386	78.77	0.1626	2.210	78.73	0.1617
60	2.893	80.40	.1677	2.646	80.36	.1666	2.436	80.32	.1656	2.257	80.29	.1647
70	2.952	81.96	.1707	2.700	81.93	1696	2.487	81.89	.1686	2.304	81.86	.1677
80	3.012	83.54	.1736	2.755	83.51	1726	2.538	83.47	.1716	2.351	83.44	.1707
90	3.071	85.13	.1765	2.809	85.10	.1755	2.588	85.07	.1745	2.399	85.03	1736
100	3.130	86.74	0.1794	2.864	86.71	0.1784	2.639	86.67	0.1774	2.446	86.64	0.1765
110	3.189	88.36	.1823	2.918	88.33	.1813	2.689	88.29	.1803	2.493	88.26	.1794
120	3.248	89.99	.1851	2.972	89.96	.1841	2.739	89.93	.1831	2.539	89.90	.1822
130	3.307	91.64	.1879	3.027	91.61	.1869	2.789	91.58	.1859	2.586	91.55	.1850
140	3.366	93.30	.1907	3.081	93.27	.1897	2.839	93.24	1887	2.633	93.21	1878
150	3.425	94.97	0.1935	3.135	94.94	0.1925	2.889	94.91	0.1915	2.679	94.88	0.1906
160	3.483	96.66	.1963	3.189	96.63	.1952	2.939	96.60	1943	2.726	96.57	.1934
170	3.542	98.36	.1990	3.243	98.33	.1979	2.989	98.31	1970	2.772	98.28	1961
180	3.601	100.08	.2017	3.297	100.05	.2006	3.039	100.02	.1997	2.818	99.99	1988
190	3.659	101.81	.2044	3.351	101.78	.2033	3.089	101.75	.2024	2.865	101.72	.2015
200	3.718	103.55	0.2070	3.404	103.52	0.2060	3.139	103.49	0.2050	2.911	103.47	0.2041
210	3.776	105.30	.2097	3.458	105.28	.2086	3.188	105.25	.2077	2.957	105.23	.2068
220	3.835	107.07	.2123	3.512	107.05	.2113	3.238	107.02	.2103	3.004	107.00	.2094
230	3.893	108.86	.2149	3.565	108.83	.2139	3.288	108.81	.2129	3.050	108.78	.2120
240	3.952	110.65	.2175	3.619	110.63	.2164	3.337	110.61	.2155	3.096	110.58	.2146
250	4.010	112.46	0.2201	3.672	112.44	0.2190	3.387	112.42	0.2181	3.142	112.39	0.2172
260	4.068	114.29	.2226	3.726	114.27	.2216	3.436	114.24	.2206	3.188	114.22	.2197
270	4.127	116.13	.2251	3.780	116.11	.2241	3.486	116.08	.2232	3.234	116.06	.2223
280	4.185	117.98	.2277	3.833	117.96	.2266	3.535	117.93	.2257	3.280	117.91	.2248
290	4.243	119.85	.2302	3.887	119.82	.2291	3.585	119.80	.2282	3.326	119.78	.2273
300	4.301	121.73	0.2327	3.940	121.70	0.2316	3.634	121.68	0.2307	3.372	121.66	0.2298
310	4.359	123.62	.2351	3.993	123.60	.2341	3.683	123.58	.2332	3.418	123.56	.2323
320	4.417	125.53	0.2376	4.047	125.51	0.2366	3.733	125.49	.2356	3.464	125.47	.2347
330	.....	.. ..	.. ..	....	....	....	3.782	127.41	0.2381	3.510	127.39	0.2372

Temp. °F.	Abs. Pressure 16 lb./in.² Gage Pressure 1.3 lb./in.² (Sat'n. Temp. 42.3° F.)			Abs. Pressure 18 lb./in.² Gage Pressure 3.3 lb./in.² (Sat'n. Temp. 48.0° F.)			Abs. Pressure 20 lb./in.² Gage Pressure 5.3 lb./in.² (Sat'n. Temp. 53.3° F.)			Abs. Pressure 22 lb./in.² Gage Pressure 7.3 lb./in.² (Sat'n. Temp. 58.1° F.)		
(At sat'n.)	(1.892)	(77.47)	(0.1577)	(1.694)	(78.27)	(0.1580)	(1.534)	(79.00)	(0.1583)	(1.403)	(79.68)	(0.1585)
50	1.924	78.66	0.1601	1.701	78.58	0.1586	......	......	......	......	......	......
60	1.965	80.21	.1631	1.738	80.14	.1616	1.557	80.06	0.1603	1.408	79.98	0.1591
70	2.007	81.78	.1661	1.776	81.71	.1646	1.591	81.64	.1633	1.439	81.56	.1621
80	2.049	83.37	.1690	1.813	83.30	.1676	1.624	83.22	.1663	1.470	83.15	.1651
90	2.090	84.96	.1720	1.850	84.90	.1705	1.658	84.82	.1692	1.501	84.75	.1681
100	2.131	86.57	0.1749	1.887	86.51	0.1734	1.692	86.44	0.1721	1.532	86.37	0.1709
110	2.173	88.20	.1778	1.924	88.13	.1763	1.725	88.07	.1750	1.562	88.00	.1738
120	2.214	89.83	.1806	1.961	89.77	.1792	1.759	89.71	.1779	1.593	89.64	.1767
130	2.255	91.48	.1834	1.998	91.42	.1820	1.792	91.36	.1807	1.623	91.30	.1795
140	2.296	93.15	.1862	2.035	93.09	.1848	1.825	93.03	.1835	1.654	92.97	.1823
150	2.337	94.83	0.1890	2.071	94.77	0.1876	1.858	94.71	0.1863	1.684	94.65	0.1851
160	2.378	96.52	.1918	2.108	96.46	.1903	1.891	96.40	.1890	1.714	96.34	.1879
170	2.419	98.22	.1945	2.144	98.16	.1931	1.924	98.11	.1918	1.745	98.05	.1906
180	2.460	99.94	.1972	2.181	99.88	.1958	1.957	99.83	.1945	1.775	99.77	.1933
190	2.500	101.67	.1999	2.217	101.62	.1984	1.990	101.56	.1972	1.805	101.51	.1960
200	2.541	103.41	0.2025	2.253	103.36	0.2011	2.023	103.31	0.1998	1.835	103.26	0.1987
210	2.582	105.17	.2052	2.290	105.12	.2038	2.056	105.07	.2025	1.865	105.02	.2013
220	2.622	106.95	.2078	2.326	106.90	.2064	2.089	106.84	.2051	1.895	106.79	.2040
230	2.663	108.73	.2104	2.362	108.68	.2090	2.122	108.63	.2077	1.925	108.58	.2066
240	2.704	110.53	.2130	2.398	110.48	.2116	2.155	110.43	.2103	1.955	110.39	.2092
250	2.744	112.35	0.2156	2.435	112.30	0.2142	2.187	112.25	0.2129	1.985	112.20	0.2117
260	2.785	114.17	.2181	2.471	114.13	.2167	2.220	114.08	.2155	2.014	114.03	.2143
270	2.825	116.01	.2207	2.507	115.97	.2193	2.252	115.92	.2180	2.044	115.88	.2168
280	2.866	117.87	.2232	2.543	117.82	.2218	2.285	117.78	.2205	2.074	117.73	.2194
290	2.906	119.74	.2257	2.579	119.69	.2243	2.317	119.65	.2230	2.104	119.60	.2219
300	2.946	121.62	0.2282	2.615	121.57	0.2268	2.350	121.53	0.2255	2.133	121.49	0.2244
310	2.986	123.51	.2307	2.651	123.47	.2293	2.382	123.43	.2280	2.163	123.39	.2269
320	3.027	125.42	.2332	2.687	125.38	.2317	2.415	125.34	.2305	2.192	125.30	.2293
330	3.067	127.35	.2356	2.723	127.30	.2342	2.447	127.26	.2329	2.222	127.22	.2318
340	3.107	129.28	0.2380	2.759	129.24	0.2366	2.480	129.20	.2354	2.252	129.16	.2342
350	......	......	......	......	......	......	2.512	131.15	0.2378	2.281	131.11	0.2367

TABLE 2A-21. PROPERTIES OF SUPERHEATED VAPOR, FREON 114 (*Continued*)

Temp. °F.	Abs. Pressure 24 lb./in.² Gage Pressure 9.3 lb./in.² (Sat'n. Temp. 62.6° F.)			Abs. Pressure 26 lb./in.² Gage Pressure 11.3 lb./in.² (Sat'n. Temp. 66.8° F.)			Abs. Pressure 28 lb./in.² Gage Pressure 13.3 lb./in.² (Sat'n. Temp. 70.8° F.)			Abs. Pressure 30 lb./in.² Gage Pressure 15.3 lb./in.² (Sat'n. Temp. 74.6° F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(At sat'n.)	(1.292)	(80.31)	(0.1588)	(1.193)	(80.90)	(0.1590)	(1.117)	(81.46)	(0.1593)	(1.046)	(81.98)	(0.1595)
70	1.313	81.49	0.1610	1.206	81.41	0.1600	......	......	......	......	......	......
80	1.341	83.08	.1640	1.233	83.00	.1630	1.139	82.93	0.1620	1.058	82.85	0.1611
90	1.370	84.68	.1670	1.259	84.61	.1659	1.164	84.54	.1650	1.082	84.47	.1641
100	1.398	86.30	0.1699	1.286	86.23	0.1688	1.189	86.16	0.1679	1.105	86.09	0.1670
110	1.427	87.93	.1727	1.312	87.86	.1717	1.213	87.79	.1708	1.128	87.73	.1699
120	1.455	89.58	.1756	1.338	89.51	.1746	1.238	89.44	.1737	1.151	89.38	.1728
130	1.483	91.23	.1784	1.364	91.17	.1774	1.262	91.10	.1765	1.174	91.04	.1756
140	1.511	92.90	.1812	1.390	92.84	.1802	1.287	92.78	.1793	1.197	92.71	.1784
150	1.539	94.58	0.1840	1.416	94.52	0.1830	1.311	94.46	0.1821	1.220	94.40	0.1812
160	1.567	96.28	.1868	1.442	96.22	.1858	1.335	96.16	.1849	1.242	96.10	.1840
170	1.595	97.99	.1895	1.468	97.93	.1885	1.359	97.88	.1876	1.265	97.82	.1867
180	1.623	99.71	.1922	1.494	99.66	.1912	1.383	99.60	.1903	1.288	99.54	.1895
190	1.651	101.45	.1949	1.520	101.40	.1939	1.407	101.34	.1930	1.310	101.28	.1922
200	1.678	103.20	0.1976	1.545	103.15	0.1966	1.431	103.09	0.1957	1.333	103.04	0.1949
210	1.706	104.96	.2003	1.571	104.91	.1993	1.455	104.86	.1984	1.355	104.81	.1975
220	1.733	106.74	.2029	1.596	106.69	.2019	1.479	106.64	.2010	1.378	106.59	.2002
230	1.761	108.53	.2055	1.622	108.48	.2045	1.503	108.43	.2036	1.400	108.38	.2028
240	1.788	110.34	.2081	1.647	110.29	.2071	1.527	110.24	.2062	1.422	110.19	.2054
250	1.816	112.15	0.2107	1.673	112.11	0.2097	1.550	112.06	0.2088	1.444	112.01	0.2079
260	1.843	113.98	.2133	1.698	113.94	.2123	1.574	113.89	.2114	1.467	113.84	.2105
270	1.871	115.83	.2158	1.724	115.78	.2148	1.598	115.74	.2139	1.489	115.69	.2131
280	1.898	117.69	.2183	1.749	117.64	.2174	1.622	117.60	.2164	1.511	117.55	.2156
290	1.925	119.56	.2208	1.774	119.51	.2199	1.645	119.47	.2190	1.533	119.42	.2181
300	1.953	121.44	0.2233	1.800	121.40	0.2224	1.669	121.36	0.2215	1.555	121.31	0.2206
310	1.980	123.34	.2258	1.825	123.30	.2249	1.692	123.26	.2240	1.577	123.21	.2231
320	2.007	125.25	.2283	1.850	125.21	.2273	1.716	125.17	.2264	1.599	125.13	.2256
330	2.034	127.18	.2307	1.875	127.14	.2298	1.739	127.10	.2289	1.621	127.06	.2280
340	2.061	129.12	.2332	1.900	129.08	.2322	1.762	129.04	.2313	1.643	129.00	.2305
350	2.088	131.07	0.2356	1.925	131.04	0.2346	1.786	131.00	0.2337	1.665	130.96	0.2329
360	2.116	133.04	0.2380	1.951	133.01	0.2371	1.809	132.97	.2362	1.687	132.93	.2353
370	......	......	......	......	......	......	1.833	134.95	0.2386	1.708	134.91	0.2377

Temp. °F.	Abs. Pressure 32 lb./in.^{2} Gage Pressure 17.3 lb./in.^{2} (Sat'n. Temp. 78.2° F.)			Abs. Pressure 34 lb./in.^{2} Gage Pressure 19.3 lb./in.^{2} (Sat'n. Temp. 81.6° F.)			Abs. Pressure 36 lb./in.^{2} Gage Pressure 21.3 lb./in.^{2} (Sat'n. Temp. 84.9° F.)			Abs. Pressure 38 lb./in.^{2} Gage Pressure 23.3 lb./in.^{2} (Sat'n. Temp. 88.0° F.)		
(At sat'n.)	(0.9836)	(82.49)	(0.1598)	(0.9284)	(82.96)	(0.1600)	(0.8792)	(83.41)	(0.1602)	(0.8347)	(83.84)	(0.1604)
80	0.9874	82.78	0.1603	......	......	......	......	......	......	......	......	......
90	1.010	84.39	.1633	0.9458	84.32	0.1625	0.8891	84.24	0.1617	0.8384	84.17	0.1610
100	1.032	86.02	0.1662	0.9666	85.95	0.1654	0.9089	85.87	0.1646	0.8573	85.80	0.1639
110	1.053	87.66	.1691	0.9873	87.59	.1683	.9286	87.52	.1675	.8761	87.44	.1668
120	1.075	89.31	.1720	1.008	89.24	.1712	.9482	89.17	.1704	.8948	89.10	.1697
130	1.097	90.97	.1748	1.028	90.91	.1740	.9677	90.84	.1733	.9134	90.77	.1726
140	1.118	92.65	.1776	1.049	92.59	.1768	0.9871	92.52	.1761	.9320	92.46	.1754
150	1.140	94.34	0.1804	1.069	94.28	0.1796	1.007	94.21	0.1789	0.9505	94.15	0.1782
160	1.161	96.04	.1832	1.090	95.98	.1824	1.026	95.92	.1817	.9689	95.86	.1810
170	1.183	97.76	.1859	1.110	97.70	.1852	1.045	97.64	.1844	0.9872	97.58	.1837
180	1.204	99.49	.1887	1.130	99.43	.1879	1.064	99.37	.1872	1.005	99.31	.1865
190	1.225	101.23	.1914	1.150	101.17	.1906	1.083	101.11	.1899	1.024	101.06	.1892
200	1.246	102.98	0.1940	1.170	102.93	0.1933	1.102	102.87	0.1926	1.042	102.82	0.1919
210	1.268	104.75	.1967	1.190	104.70	.1959	1.121	104.64	.1952	1.060	104.59	.1945
220	1.289	106.53	.1993	1.210	106.48	.1986	1.140	106.43	.1979	1.078	106.38	.1972
230	1.310	108.33	.2020	1.230	108.28	.2012	1.159	108.23	.2005	1.096	108.18	.1998
240	1.331	110.14	.2046	1.250	110.09	.2038	1.178	110.04	.2031	1.113	109.99	.2024
250	1.352	111.96	0.2072	1.269	111.91	0.2064	1.197	111.86	0.2057	1.131	111.81	0.2050
260	1.372	113.79	.2097	1.289	113.75	.2090	1.215	113.70	.2083	1.149	113.65	.2076
270	1.393	115.64	.2123	1.309	115.60	.2115	1.234	115.55	.2108	1.167	115.50	.2101
280	1.414	117.50	.2148	1.328	117.46	.2141	1.253	117.41	.2133	1.185	117.37	.2127
290	1.435	119.38	.2173	1.348	119.33	.2166	1.271	119.29	.2159	1.203	119.25	.2152
300	1.455	121.27	0.2198	1.368	121.22	0.2191	1.290	121.18	0.2184	1.220	121.14	0.2177
310	1.476	123.17	.2223	1.387	123.13	.2216	1.308	123.08	.2209	1.238	123.04	.2202
320	1.497	125.09	.2248	1.407	125.05	.2241	1.327	125.00	.2233	1.255	124.96	.2227
330	1.517	127.02	.2272	1.426	126.98	.2265	1.345	126.93	.2258	1.273	126.89	.2251
340	1.538	128.96	.2297	1.446	128.92	.2289	1.364	128.88	.2283	1.290	128.84	.2276
350	1.559	130.92	0.2321	1.465	130.88	0.2314	1.382	130.84	0.2307	1.308	130.80	0.2300
360	1.579	132.89	.2345	1.485	132.85	.2338	1.401	132.81	.2331	1.325	132.77	.2324
370	1.600	134.87	0.2370	1.504	134.83	.2362	1.419	134.79	.2355	1.343	134.75	.2348
380	......	......	......	1.524	136.83	0.2386	1.437	136.79	0.2379	1.360	136.75	0.2372

TABLE 2A-21. PROPERTIES OF SUPERHEATED VAPOR, FREON 114 (*Continued*)

Temp. °F.	Abs. Pressure 40 lb/in.^{2} Gage Pressure 25.3 lb./in.^{2} (Sat'n. Temp. 91.0° F.)			Abs. Pressure 45 lb./in.^{2} Gage Pressure 30.3 lb/in.^{2} (Sat'n. Temp. 98.1° F.)			Abs. Pressure 50 lb/in.^{2} Gage Pressure 35.3 lb/in.^{2} (Sat'n. Temp. 104.6° F.)			Abs. Pressure 55 lb./in.^{2} Gage Pressure 40.3 lb./in.^{2} (Sat'n. Temp. 110.7° F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
(At sat'n.)	(0.7948)	(84.25)	(0.1606)	(0.7095)	(85.23)	(0.1611)	(0.6408)	(86.10)	(0.1616)	(0.5841)	(86.92)	(0.1620)
100	0.8108	85.73	0.1632	0.7125	85.54	0.1616	......	......	......	......	......	......
110	.8288	87.37	.1661	.7288	87.19	.1646	0.6487	87.00	0.1631	......	......	......
120	.8467	89.03	.1690	.7450	88.86	.1675	.6636	88.68	.1660	0.5967	88.49	0.1647
130	.8646	90.70	.1719	.7611	90.53	.1703	.6784	90.36	.1689	.6104	90.18	.1676
140	.8824	92.39	.1747	.7772	92.22	.1732	.6931	92.05	.1718	.6240	91.88	.1705
150	0.9001	94.09	0.1775	0.7932	93.92	0.1760	0.7077	93.76	0.1746	0.6375	93.59	0.1733
160	.9176	95.80	.1803	.8091	95.64	.1788	.7223	95.48	.1774	.6509	95.31	.1761
170	.9351	97.52	.1831	.8250	97.37	.1816	.7367	97.21	.1802	.6643	97.05	.1789
180	.9524	99.25	.1858	.8407	99.11	.1843	.7511	98.95	.1829	.6776	98.80	.1816
190	.9697	101.00	.1885	.8563	100.86	.1870	.7654	100.71	.1856	.6908	100.56	.1844
200	0.9870	102.76	0.1912	0.8719	102.62	0.1897	0.7796	102.48	0.1883	0.7039	102.33	0.1871
210	1.004	104.53	.1939	.8874	104.40	.1924	.7937	104.26	.1910	.7170	104.12	.1898
220	1.021	106.32	.1965	.9028	106.19	.1950	.8077	106.05	.1937	.7300	105.91	.1924
230	1.039	108.12	.1992	.9182	107.99	.1977	.8217	107.86	.1963	.7429	107.72	.1951
240	1.056	109.93	.2018	.9335	109.81	.2003	.8357	109.68	.1989	.7558	109.55	.1977
250	1.073	111.76	0.2044	0.9488	111.64	0.2029	0.8496	111.51	0.2015	0.7686	111.38	0.2003
260	1.090	113.60	.2069	.9641	113.48	.2055	.8635	113.35	.2041	.7813	113.23	.2029
270	1.107	115.45	.2095	.9793	115.33	.2080	.8773	115.21	.2067	.7940	115.09	.2054
280	1.124	117.32	.2120	0.9945	117.20	.2106	.8911	117.08	.2092	.8066	116.97	.2080
290	1.141	119.20	.2146	1.010	119.08	.2131	.9049	118.97	.2118	.8192	118.85	.2105
300	1.157	121.09	0.2171	1.025	120.98	0.2156	0.9186	120.87	0.2143	0.8318	120.75	0.2130
310	1.174	123.00	.2196	1.040	122.89	.2181	.9323	122.78	.2168	.8444	122.67	.2155
320	1.191	124.92	.2220	1.055	124.81	.2206	.9460	124.70	.2193	.8569	124.59	.2180
330	1.208	126.85	.2245	1.070	126.75	.2230	.9597	126.64	.2217	.8694	126.53	.2205
340	1.224	128.80	.2270	1.085	128.70	.2255	.9733	128.59	.2242	.8819	128.49	.2230
350	1.241	130.76	0.2294	1.100	130.66	0.2279	0.9868	130.55	0.2266	0.8943	130.45	0.2254
360	1.258	132.73	.2318	1.115	132.63	.2304	1.000	132.53	.2290	.9067	132.43	.2278
370	1.274	134.72	.2342	1.130	134.62	.2328	1.014	134.52	.2315	.9191	134.42	.2303
380	1.291	136.72	.2366	1.144	136.62	.2352	1.027	136.53	.2339	.9314	136.43	.2327
390	1.308	138.73	0.2390	1.159	138.63	0.2376	1.041	138.54	.2362	.9437	138.45	.2351
400	......	......	......	......	......	......	1.054	140.57	0.2386	0.9560	140.48	0.2374
410	......	......	......	......	......	......	......	......	......	0.9683	142.53	0.2398

Temp. t	Abs. Pressure 60 lb./in.^{2} Gage Pressure 45.3 lb./in.^{2} (Sat'n. Temp. 116.3° F.)			Abs. Pressure 65 lb./in.^{2} Gage Pressure 50.3 lb./in.^{2} (Sat'n. Temp. 121.6° F.)			Abs. Pressure 70 lb./in.^{2} Gage Pressure 55.3 lb./in.^{2} (Sat'n. Temp. 126.6° F.)			Abs. Pressure 75 lb./in.^{2} Gage Pressure 60.3 lb./in.^{2} (Sat'n. Temp. 131.4° F.)		
(At sat'n.)	(0.5364)	(87.67)	(0.1624)	(0.4958)	(88.37)	(0.1628)	(0.4607)	(89.03)	(0.1632)	(0.4302)	(89 65)	(0.1635)
120	0.5411	88.30	0.1635	......	......	......	......	......	......	......	......	......
130	.5539	90.00	.1664	0.5059	89.81	0.1652	0.4645	89.62	0.1642	......	......	......
140	.5666	91.70	.1693	.5179	91.52	.1681	.4759	91.34	.1670	0.4395	91.15	0.1660
150	0.5792	93.42	0.1721	0.5298	93.25	0.1710	0.4873	93.07	0.1699	0.4502	92.89	0.1689
160	.5918	95.15	.1749	.5415	94.98	.1738	.4985	94.81	.1727	.4608	94.63	.1717
170	.6043	96.89	.1777	.5532	96.73	.1766	.5095	96.56	.1755	.4713	96.39	.1745
180	.6166	98.64	.1805	.5648	98.49	.1794	.5204	98.33	.1783	.4817	98.16	.1773
190	.6288	100.41	.1832	.5763	100.26	.1821	.5312	100.10	.1811	.4920	99.94	.1801
200	0.6410	102.18	0.1859	0.5876	102.04	0.1848	0.5419	101.88	0.1838	0.5022	101.73	0.1828
210	.6530	103.97	.1886	.5989	103.83	.1875	.5525	103.68	.1865	.5122	103.53	.1855
220	.6650	105.78	.1913	.6101	105.63	.1902	.5630	105.49	.1892	.5222	105.35	.1882
230	.6770	107.59	.1939	.6213	107.45	.1928	.5735	107.31	.1918	.5322	107.17	.1909
240	.6889	109.41	.1965	.6324	109.28	.1955	.5840	109.15	.1945	.5421	109.01	.1935
250	0.7008	111.25	0.1991	0.6435	111.12	0.1981	0.5944	110.99	0.1971	0.5519	110 86	0.1962
260	.7126	113.10	.2017	.6545	112.98	.2007	.6048	112.85	.1997	.5617	112.72	.1988
270	.7244	114.97	.2043	.6655	114.85	.2033	.6151	114.72	.2023	.5715	114.59	.2014
280	.7362	116.85	.2069	.6765	116.73	.2058	.6254	116.60	.2048	.5812	116.48	.2040
290	.7479	118.74	.2094	.6874	118.62	.2084	.6356	118.50	.2074	.5908	118.38	.2065
300	0.7595	120.64	0.2119	0.6983	120.52	0.2109	0.6458	120.41	0.2099	0.6004	120.29	0.2090
310	.7711	122.56	.2144	.7091	122.44	.2134	.6559	122.33	.2124	.6099	122.22	.2115
320	.7827	124.49	.2169	.7199	124.37	.2159	.6660	124.26	.2149	.6194	124.15	.2140
330	.7943	126.43	.2194	.7307	126.32	.2184	.6761	126.21	.2174	.6289	126.10	.2165
340	.8058	128.38	.2219	.7414	128.28	.2208	.6862	128.17	.2199	.6383	128.06	.2190
350	0.8173	130.35	0.2243	0.7521	130.25	0.2233	0.6962	130.14	0.2223	0.6477	130.04	0.2214
360	.8287	132.33	.2267	.7627	132.23	.2257	.7062	132.13	.2248	.6571	132.03	.2239
370	.8401	134.33	.2292	.7733	134.23	.2281	.7161	134.13	.2272	.6664	134.03	.2263
380	.8515	136.34	.2316	.7839	136.24	.2305	.7260	136.14	.2296	.6757	136.04	.2287
390	.8629	138.36	.2340	.7945	138.26	.2329	.7359	138.17	.2320	.6850	138.07	.2311
400	0 8742	140.39	0.2363	0.8050	140.30	0.2353	0.7458	140.21	0.2344	0.6943	140.11	0.2335
410	0.8855	142.44	0.2387	.8155	142.35	.2377	.7556	142.26	.2368	.7036	142.16	.2359
420	......	......	......	0.8260	144.41	0.2401	0.7654	144.32	0.2391	.7128	144.23	.2382
430	......	......	......	......	......	......	......	......	......	0.7220	146.31	0.2406

TABLE 2A-21. PROPERTIES OF SUPERHEATED VAPOR, FREON 114 (*Continued*)

Temp. °F.	Abs. Pressure 80 lb./in.^{2} Gage Pressure 65.3 lb./in.^{2} (Sat'n. Temp. 135.9° F.)			Abs. Pressure 85 lb./in.^{2} Gage Pressure 70.3 lb./in.^{2} (Sat'n. Temp. 140.2° F.)		
t	V	H	S	V	H	S
(At sat'n.)	(0.4033)	(90.24)	(0.1638)	(0.3794)	(90.78)	(0.1641)
140	0.4076	90.96	0.1650	......	......	......
150	0.4178	92.70	0.1679	0.3890	92.51	0.1670
160	.4279	94.46	.1708	.3988	94.27	.1699
170	.4379	96.22	.1736	.4084	96.04	.1727
180	.4478	97.99	.1764	.4179	97.83	.1755
190	.4576	99.78	.1792	.4273	99.62	.1783
200	0.4674	101.58	0.1819	0.4366	101.42	0.1811
210	.4770	103.38	.1846	.4458	103.23	.1838
220	.4865	105.20	.1873	.4548	105.05	.1865
230	.4959	107.03	.1900	.4638	106.89	.1892
240	.5053	108.87	.1927	.4728	108.73	.1918
250	0.5146	110.72	0.1953	0.4817	110.59	0.1944
260	.5239	112.59	.1979	.4905	112.46	.1971
270	.5331	114.47	.2005	.4993	114.34	.1996
280	.5423	116.36	.2031	.5081	116.23	.2022
290	.5514	118.26	.2056	.5168	118.14	.2048
300	0.5605	120.17	0.2081	0.5254	120.05	0.2073
310	.5695	122.10	.2107	.5340	121.98	.2099
320	.5785	124.04	.2132	.5426	123.93	.2124
330	.5875	125.99	.2157	.5511	125.88	.2149
340	.5964	127.96	.2181	.5595	127.85	.2173
350	0.6053	129.93	0.2206	0.5679	129.83	0.2198
360	.6142	131.92	.2230	.5763	131.82	.2222
370	.6230	133.93	.2255	.5847	133.83	.2247
380	.6318	135.94	.2279	.5930	135.85	.2271
390	.6406	137.97	.2303	.6013	137.88	.2295
400	0.6494	140.02	0.2327	0.6096	139.92	0.2319
410	.6581	142.07	.2351	.6179	141.98	.2343
420	.6668	144.14	.2374	.6262	144.05	.2366
430	0.6755	146.22	0.2398	.6344	146.13	.2390
440	......	......	......	0.6426	148.23	0.2413

ETHYLENE

TABLE 2A-22. PROPERTIES OF SATURATED ETHYLENE BELOW THE NORMAL BOILING POINT

(*By permission, Robert York Jr., and E. F. White*)

Temp., °F.	Vapor Pressure		Gas Volume, cu. ft./lb. v_g	Enthalpy, Btu/lb.			Entropy, Btu/lb. °R.		
	mm. Hg	Absolute, lbs./in.^{2}		h_f	h_{fg}	h_g	s_f	s_{fg}	s_g
-154.66 *	760.0	14.70	7.671	0.00	207.9	207.9	0.0000	0.682	0.682
-160.0	635.9	12.30	9.047	- 3.12	210.3	207.2	-0.0103	0.702	0.692
-180.0	305.0	5.90	17.92	-14.57	217.2	202.6	-0.0498	0.777	0.727
-200.0	128.5	2.48	39.74	-26.03	223.1	197.1	-0.0922	0.859	0.767
-220.0	45.9	0.89	103.1	-37.56	229.0	191.4	-0.1382	0.955	0.817
-240.0	13.2	0.26	328.6	-49.16	234.9	185.7	-0.1887	1.069	0.880
-260.0	2.85	0.055	1405.0	-60.84	240.9	180.1	-0.2351	1.207	0.972
-272.47 †	0.91	0.018	4064.0	-68.19	244.7	176.5	-0.2826	1.307	1.024

* Normal boiling point.
† Melting point.

TABLE 2A-23. PROPERTIES OF THE SATURATED ETHYLENE LIQUID AND SATURATED VAPOR

(*By permission, Robert York Jr., and E. F. White*)

Temp., °F.	Absolute Pressure, atm.	Volume, cu. ft./lb.		Enthalpy, Btu/lb			Entropy, Btu/lb. °R.		
		v_f	v_g	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g
-154.66 *	1.0000	0.02818	7.6712	0.0	207.9	207.9	0.0000	0.6814	0.6814
-140.00	1.5775	0.02877	5.005	8.6	201.9	210.5	0.0249	0.6314	0.6563
-120.00	2.7376	0.02964	2.987	20.8	193.4	214.2	0.0648	0.5692	0.6340
-100.00	4.4616	0.03122	1.879	32.8	184.4	217.2	0.0995	0.5126	0.6121
- 80.00	6.8697	0.03179	1.732	45.2	174.7	219.9	0.1374	0.4600	0.5974
- 60.00	10.099	0.03308	0.857	57.9	164.0	221.9	0.1666	0.4103	0.5769
- 40.00	14.0338	0.03468	0.593	70.8	152.0	222.8	0.1935	0.3621	0.5556
- 20.00	19.722	0.03662	0.419	84.7	138.0	222.7	0.2245	0.3138	0.5383
0.00	26.397	0.03912	0.301	100.3	120.7	221.0	0.2577	0.2625	0.5202
+ 20.00	34.55	0.04292	0.212	119.6	97.02	216.6	0.2968	0.2023	0.4991
+ 40.00	44.54	0.05035	0.139	148.7	57.46	206.2	0.3533	0.1150	0.4683
+ 49.82 †	50.50	0.070	0.070	171.8	0.00	171.8	0.3964	0.0000	0.3964

* Normal boiling point.
† Critical temperature.

THERMODYNAMIC PROPERTIES OF ETHYLENE

TABLE 2A-24. VALUES OF THE VOLUME, ENTHALPY, AND ENTROPY OF THE SUPERHEATED VAPOR

(*Courtesy Robert York Jr., and E. F. White*)

Absolute Pressure		Temperature, °F.										
		−140°	−120°	−100°	−80°	−60°	−40°	−20°	0°	20°	40°	60°
1 atm.	*V*	8.061	8.617	9.168	9.714	10.256	10.794	11.329	11.862	12.497	12.924	13.453
	H	212.2	218.3	224.3	230.6	236.9	243.3	249.9	256.6	263.4	270.4	277.7
	S	0.695	0.714	0.732	0.748	0.764	0.780	0.795	0.810	0.825	0.839	0.853
2 atm.	*V*		4.190	4.479	4.765	5.047	5.324	5.599	5.873	6.144	6.414	6.683
	H		215.9	222.3	228.9	235.4	242.0	248.7	255.6	262.5	269.5	276.9
	S		0.659	0.677	0.693	0.710	0.726	0.741	0.756	0.771	0.785	0.799
4 atm.	*V*			2.130	2.287	2.439	2.588	2.733	2.878	3.019	3.159	3.297
	H			218.2	225.5	232.4	239.3	246.3	253.4	260.6	267.8	275.3
	S			0.623	0.641	0.658	0.675	0.691	0.706	0.722	0.737	0.751
6 atm.	*V*				1.456	1.566	1.673	1.776	1.833	1.877	2.099	2.168
	H				221.6	229.1	236.6	243.9	251.2	258.6	266.0	273.7
	S				0.607	0.625	0.642	0.659	0.675	0.691	0.706	0.721
8 atm.	*V*					1.126	1.213	1.296	1.376	1.453	1.529	1.604
	H					225.7	233.6	241.3	249.0	256.6	264.2	272.1
	S					0.599	0.618	0.634	0.651	0.668	0.683	0.698
10 atm.	*V*					0.860	0.936	1.006	1.074	1.140	1.202	1.264
	H					222.4	230.8	238.8	246.6	254.4	262.4	270.4
	S					0.578	0.599	0.616	0.632	0.649	0.665	0.680
15 atm.	*V*							0.614	0.669	0.718	0.765	0.811
	H							230.9	239.9	248.7	257.5	266.2
	S							0.573	0.593	0.612	0.630	0.646
20 atm.	*V*								0.459	0.503	0.545	0.583
	H								232.5	242.5	252.1	261.3
	S								0.560	0.582	0.591	0.618
25 atm.	*V*								0.330	0.373	0.409	0.443
	H								223.9	235.4	246.3	256.4
	S								0.530	0.554	0.576	0.595

30 atm.	*V*	.....	.....	.....	.....	.....	.....	.....	.....	0.282	0.318	0.350
	H	.....	.....	.....	.....	.....	.....	.....	.....	226.9	239.5	250.8
	S	.....	.....	.....		.....	.....		.....	0.528	0.552	0.574
35 atm.	*V*	.....	.....					.....	.....	.....	0.250	0.281
	H	.....							.....	.....	231.4	243.6
	S	.....				.....	.....	.....	.....	.....	0.529	0.554
40 atm.	*V*	.....	.....							.....	0.192	0.228
	H	.....						.....			221.1	237.3
	S	.....									0.503	0.534
50 atm.	*V*	.....									.....	0.138
	H	.....									.....	218.1
	S	.....									.....	0.484
60 atm.	*V*											0.069
	H										.....	171.0
	S											0.390
80 atm.	*V*											0.051
	H											146.4
	S											0.340
100 atm.	*V*											0.044
	H										.....	143.5
	S											0.327
120 atm.	*V*										.....	0.045
	H	.....										139.3
	S	.....							.....		.....	0.319
150 atm.	*V*											0.039
	H											139.1
	S									.....		0.308
200 atm.	*V*	.....										0.037
	H						.....	.....			.....	138.3
	S		.....					.....	.....	.....	.....	0.295
250 atm.	*V*	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.035
	H	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	138.2
	S	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.286
300 atm.	*V*	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.034
	H	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	137.9
	S	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.277

TABLE 2A-24. VALUES OF THE VOLUME, ENTHALPY, AND ENTROPY OF THE SUPERHEATED VAPOR, ETHYLENE (*Continued*)

Absolute Pressure		Temperature °F.										
		80°	100°	120°	140°	160°	180°	200°	220°	240°	260°	280°
1 atm.	*V*	13.98	14.51	15.04	15.56	16.09	16.61	17.14	17.66	18.19	18.71	19.23
	H	285.0	292.6	300.4	308.3	316.4	324.8	333.4	342.0	350.9	360.0	369.3
	S	0.867	0.831	0.894	0.908	0.921	0.934	0.948	0.961	0.974	0.986	0.999
2 atm.	*V*	6.950	7.217	7.484	7.749	8.015	8.280	8.544	8.808	9.07	9.34	9.60
	H	284.2	291.9	299.7	307.6	315.8	324.2	332.9	341.5	350.5	359.7	369.0
	S	0.814	0.828	0.841	0.855	0.868	0.881	0.895	0.909	0.922	0.934	0.947
4 atm.	*V*	3.435	3.571	3.707	3.843	3.978	4.113	4.247	4.380	4.514	4.647	4.781
	H	282.8	290.6	298.6	306.6	314.8	323.3	332.0	340.6	349.7	358.9	368.2
	S	0.765	0.780	0.793	0.807	0.820	0.833	0.847	0.860	0.873	0.886	0.899
6 atm.	*V*	2.263	2.356	2.448	2.541	2.633	2.724	2.814	2.905	2.994	3.084	3.174
	H	281.4	289.3	297.3	305.4	313.7	322.3	331.0	339.8	348.8	358.1	367.5
	S	0.735	0.750	0.763	0.777	0.791	0.804	0.818	0.831	0.844	0.856	0.870
8 atm.	*V*	1.676	1.753	1.818	1.889	1.960	2.029	2.097	2.167	2.235	2.303	2.371
	H	279.9	287.9	296.1	304.3	312.7	321.3	330.1	338.9	348.0	357.3	366.7
	S	0.713	0.728	0.741	0.756	0.770	0.783	0.797	0.810	0.823	0.836	0.849
10 atm.	*V*	1.324	1.382	1.458	1.499	1.556	1.613	1.668	1.724	1.779	1.834	1.889
	H	278.4	286.5	294.8	303.1	311.6	320.3	329.2	338.0	347.2	356.5	366.0
	S	0.696	0.711	0.724	0.739	0.753	0.766	0.781	0.794	0.808	0.820	0.833
15 atm.	*V*	0.854	0.897	0.937	0.978	1.018	1.057	1.094	1.134	1.172	1.209	1.247
	H	274.5	283.0	291.5	300.1	308.8	317.7	326.8	335.8	345.1	354.6	364.2
	S	0.661	0.677	0.692	0.707	0.720	0.734	0.749	0.763	0.776	0.789	0.802
20 atm.	*V*	0.617	0.652	0.685	0.717	0.748	0.778	0.808	0.838	0.868	0.897	0.926
	H	270.2	279.2	288.1	296.9	305.9	315.1	324.3	333.5	343.0	352.6	362.3
	S	0.635	0.651	0.666	0.682	0.696	0.710	0.726	0.740	0.753	0.766	0.780
25 atm.	*V*	0.475	0.504	0.532	0.559	0.585	0.611	0.635	0.661	0.685	0.709	0.733
	H	265.9	275.3	284.6	293.8	303.0	312.4	321.8	331.2	340.7	350.4	360.3
	S	0.613	0.630	0.646	0.662	0.677	0.691	0.707	0.721	0.735	0.749	0.762

30 atm.	*V*	0.379	0.405	0.430	0.454	0.478	0.498	0.522	0.543	0.563	0.585	0.605
	H	261.2	271.2	280.7	290.2	299.8	309.5	319.2	328.7	338.5	348.3	358.3
	S	0.594	0.613	0.629	0.646	0.661	0.676	0.691	0.706	0.720	0.734	0.748
35 atm.	*V*	0.309	0.333	0.357	0.379	0.399	0.419	0.439	0.458	0.477	0.495	0.514
	H	256.1	266.8	276.8	286.7	296.7	306.6	316.5	326.2	336.2	346.3	356.4
	S	0.586	0.596	0.613	0.631	0.647	0.662	0.678	0.692	0.707	0.720	0.734
40 atm.	*V*	0.255	0.279	0.302	0.323	0.341	0.359	0.378	0.395	0.412	0.428	0.445
	H	250.2	262.3	273.0	283.4	293.5	303.7	313.8	323.8	333.9	344.1	354.4
	S	0.558	0.580	0.598	0.617	0.634	0.650	0.666	0.681	0.695	0.709	0.723
50 atm.	*V*	0.176	0.201	0.223	0.243	0.259	0.275	0.292	0.309	0.321	0.334	0.348
	H	235.5	250.3	264.2	275.6	286.6	297.5	308.3	318.7	329.2	339.7	350.2
	S	0.523	0.550	0.571	0.590	0.609	0.626	0.640	0.659	0.674	0.688	0.703
60 atm.	*V*	0.114	0.144	0.170	0.186	0.205	0.219	0.234	0.248	0.260	0.273	0.285
	H	217.3	238.9	253.7	267.4	279.5	291.2	302.6	313.6	324.5	335.4	346.1
	S	0.472	0.517	0.545	0.568	0.588	0.607	0.624	0.640	0.656	0.671	0.687
80 atm.	*V*	0.065	0.082	0.103	0.121	0.137	0.150	0.163	0.174	0.185	0.195	0.205
	H	176.3	205.0	228.3	243.3	263.4	277.6	290.5	302.8	314.7	326.4	337.7
	S	0.394	0.477	0.488	0.522	0.548	0.569	0.589	0.608	0.625	0.641	0.657
100 atm.	*V*	0.050	0.057	0.069	0.082	0.097	0.109	0.121	0.131	0.141	0.149	0.158
	H	161.3	182.5	206.7	228.3	246.5	263.0	277.8	291.3	304.4	317.1	329.2
	S	0.363	0.401	0.441	0.480	0.509	0.535	0.559	0.579	0.598	0.614	0.632
120 atm.	*V*	0.050	0.054	0.058	0.068	0.077	0.086	0.096	0.104	0.113	0.120	0.128
	H	155.9	173.9	193.7	213.2	232.2	249.8	266.0	280.9	294.9	308.4	321.0
	S	0.348	0.380	0.414	0.448	0.478	0.506	0.532	0.555	0.575	0.593	0.611
150 atm.	*V*	0.043	0.046	0.050	0.056	0.062	0.067	0.074	0.081	0.087	0.094	0.100
	H	153.0	167.7	183.5	199.8	217.3	235.0	251.6	267.2	282.1	296.5	309.8
	S	0.334	0.361	0.388	0.417	0.446	0.474	0.500	0.524	0.545	0.564	0.583
200 atm.	*V*	0.039	0.042	0.044	0.047	0.050	0.054	0.057	0.062	0.066	0.070	0.075
	H	150.9	163.8	177.1	191.1	206.1	221.5	237.1	252.3	267.2	281.7	295.6
	S	0.318	0.342	0.366	0.392	0.416	0.440	0.464	0.487	0.509	0.529	0.548
250 atm.	*V*	0.037	0.039	0.042	0.043	0.046	0.049	0.051	0.054	0.057	0.059	0.062
	H	149.8	161.8	174.3	187.5	201.0	215.1	229.7	243.9	258.1	272.3	286.2
	S	0.309	0.331	0.353	0.376	0.398	0.419	0.441	0.462	0.483	0.503	0.523
300 atm.	*V*	0.036	0.038	0.039	0.041	0.043	0.045	0.047	0.049	0.051	0.054	0.056
	H	149.5	161.4	173.7	186.3	199.0	212.1	225.3	238.7	252.2	265.9	279.9
	S	0.300	0.322	0.342	0.364	0.384	0.404	0.426	0.446	0.466	0.484	0.504

BUTANE

TABLE 2A-25. PROPERTIES OF BUTANE

Chemical symbol	C_4H_{10}
Weight of liquid, lbs. per cu. ft.	37.5
Boiling point, °F.	33.1
Freezing point, °F.	−211
Latent heat of vaporization, atmospheric pressure, Btu	165.2
Conditions at critical point:	
Temperature, °F.	551.3
Pressure, lbs. abs.	303
Pressure in evaporator at 5° F., lbs. abs.	8.2
Pressure in condenser at 86° F., lbs. abs.	41.6
Toxicity, Underwriters Grouping.	5
Inflammability	Inflammable

TABLE 2A-26. PROPERTIES OF SATURATED BUTANE

(Compiled by Linde Air Products Co.
Arranged by A.S.R.E. Published by permission)

Temp.	Pressure		Volume		Density		Enthalpy Above 0° F			Entropy From 0° F.		Temp.
° F.	Abs. lb./in.²	Gage lb./in.²	Liquid ft.³/lb.	Vapor ft.³/lb.	Liquid lb./ft.³	Vapor lb./ft.³	Liquid Btu./lb.	Latent Btu./lb.	Vapor Btu./lb.	Liquid Btu./lb.°F.	Vapor Btu./lb.°F.	° F.
t	*p*	*g p*	*v*	*V*	*1/v*	*1/V*	*h*	*L*	*H*	*s*	*S*	*t*
0	7.3	15.0*	0.02591	11.1	38.59	0.0901	0.0	170.5	170.5	0.000	0.370	0
1	7.5	14.7	.02593	10.9	38.56	.0917	0.5	170.5	171.0	.001	.370	1
2	7.7	14.3	.02596	10.7	38.52	.0935	1.0	170.0	171.0	.002	.370	2
3	7.8	13.9	.02598	10.4	38.49	.0962	1.5	170.0	171.5	.003	.370	3
4	8.0	13.6	.02601	10.2	38.45	.0980	2.0	170.0	172.0	.005	.370	4
5‡	8.2	13.2*	0.02603	9.98	38.41	0.100	2.5	169.5	172.0	0.006	0.370	5‡
6	8.4	12.8	.02606	9.78	38.38	.102	3.0	169.5	172.5	.007	.370	6
7	8.6	12.4	.02608	9.57	38.35	.104	3.5	169.5	173.0	.008	.370	7
8	8.8	12.0	.02610	9.37	38.31	.107	4.0	169.5	173.5	.009	.370	8
9	9.0	11.6	.02612	9.16	38.28	.109	4.5	169.0	173.5	.010	.370	9
10	9.2	11.1*	0.02615	8.95	38.24	0.112	5.5	168.5	174.0	0.011	0.370	10
11	9.4	10.7	.02617	8.73	38.21	.114	6.0	168.5	174.5	.012	.370	11
12	9.7	10.3	.02619	8.59	38.18	.116	6.5	168.5	175.0	.013	.370	12
13	9.9	9.9	.02622	8.41	38.14	.119	7.0	168.0	175.0	.015	.370	13
14	10.1	9.5	.02624	8.22	38.11	.122	7.5	168.0	175.5	.016	.370	14
15	10.4	8.8*	0.02627	8.05	38.07	0.124	8.0	168.0	176.0	0.017	0.370	15
16	10.6	8.5	.02629	7.88	38.04	.127	8.5	167.5	176.0	.018	.371	16
17	10.8	8.0	.02632	7.72	38.00	.130	9.0	167.5	176.5	.019	.371	17
18	11.1	7.5	.02634	7.56	37.97	.132	9.5	167.5	177.0	.020	.371	18
19	11.3	7.0	.02636	7.40	37.93	.135	10.0	167.5	177.5	.021	.371	19

20	11.6	6.3*	0.02639	7.23	37.89	0.138	10.5	167.0	177.5	0.022	0.371	**20**
21	11.8	6.0	.02641	7.10	37.86	.141	11.0	167.0	178.0	.023	.371	21
22	12.1	5.5	.02643	6.97	37.83	.143	11.5	167.0	178.5	.025	.371	22
23	12.4	4.9	.02646	6.82	37.79	.147	12.0	166.5	178.5	.026	.371	23
24	12.7	4.3	.02648	6.68	37.76	.150	12.5	166.5	179.0	.027	.371	24
25	13.0	3.6*	0.02651	6.55	37.72	0.153	13.0	166.0	179.0	0.028	0.371	**25**
30	14.4	0.6*	.02664	5.90	37.54	.169	16.0	165.5	181.5	.033	.371	30
35	16.0	1.3	.02676	5.37	37.37	.186	19.0	164.5	183.5	.039	.371	35
40	17.7	3.0	.02689	4.88	37.19	.205	21.5	163.5	185.0	.044	.371	40
45	19.6	4.9	.02703	4.47	37.00	.224	24.5	162.5	187.0	.050	.372	45
50	21.6	6.9	0.02716	4.07	36.82	0.246	27.0	161.5	188.5	0.056	0.373	**50**
55	23.8	9.1	.02730	3.73	36.63	.268	30.0	160.5	190.5	.061	.373	55
60	26.3	11.6	.02743	3.40	36.45	.294	33.0	159.5	192.5	.067	.374	60
65	28.9	14.2	.02759	3.12	36.24	.321	36.0	158.5	194.5	.072	.374	65
70	31.6	16.9	.02773	2.88	36.06	.347	38.5	157.5	196.0	.078	.375	70
75	34.5	19.8	0.02789	2.65	35.86	0.377	41.5	156.5	198.0	0.083	0.375	**75**
80	37.6	22.9	.02805	2.46	35.65	.407	44.5	155.0	199.5	.089	.376	80
85	40.9	26.2	.02821	2.28	35.45	.439	47.5	154.0	201.5	.094	.376	85
86†	**41.6**	**26.9**	**.02825**	**2.24**	**35.40**	**.446**	**48.5**	**153.5**	**202.0**	**.095**	**.376**	**86**†
90	44.5	29.8	.02838	2.10	35.24	.476	51.0	152.0	203.0	.100	.377	90
95	48.2	33.5	0.02854	1.96	35.04	0.510	54.0	151.0	205.0	0.105	0.377	**95**
100	52.2	37.5	.02870	1.81	34.84	.552	57.0	149.5	206.5	.111	.378	100
105	56.4	41.7	.02889	1.70	34.62	.588	60.5	148.0	208.5	.117	.380	105
110	60.8	46.1	.02906	1.58	34.41	.633	63.5	147.0	210.5	.122	.380	110
115	65.6	50.9	.02925	1.48	34.19	.676	66.5	145.5	212.0	.128	.381	115
120	70.8	56.1	0.02945	1.38	33.96	0.725	70.0	143.5	213.5	0.134	0.382	**120**
125	76.0	61.3	.02966	1.30	33.72	.769	73.5	142.0	215.5	.139	.382	125
130	81.4	66.7	.02986	1.21	33.49	.826	76.5	140.5	217.0	.145	.384	130
135	87.0	72.3	.03009	1.14	33.23	.877	80.0	139.0	219.0	.151	.385	135
140	92.6	77.9	.03032	1.07	32.98	.934	83.5	137.5	221.0	.157	.386	140

* Inches of Mercury below one standard atmosphere (29.92 in. = 14.696 lbs./sq. in. abs.)
† Standard Ton Temperatures.

ISOBUTANE

TABLE 2A-27. PROPERTIES OF ISOBUTANE

Chemical symbol	C_4H_{10}
Weight of liquid, lbs. per cu. ft.	37.16
Boiling point, atmospheric, lbs. abs.	10.6
Freezing point, atmospheric, °F.	−229
Latent heat of vaporization, atmospheric, Btu.	158.2
Pressure in evaporator at 5° F., lbs. abs.	13.1
Pressure in condenser at 86° F., lbs. abs.	59.5
Conditions at critical point:	
Temperature, °F.	272.7
Pressure, lbs. abs.	537
Toxicity, Underwriters Grouping	5
Inflammability	Inflammable

TABLE 2A-28. PROPERTIES OF SATURATED ISOBUTANE

(*Compiled by Linde Air Products Co.*

Arranged by A.S.R.E Published by permission)

Temp.	Pressure		Volume		Density		Enthalpy Above 0° F.			Entropy From 0° F.		Temp.
° F	Abs. lb./in.²	Gage lb./in.²	Liquid ft.³/lb.	Vapor ft.³/lb.	Liquid lb./ft.³	Vapor lb./ft.³	Liquid Btu./lb.	Latent Btu./lb.	Vapor Btu./lb	Liquid Btu./lb.°F	Vapor Btu./lb.°F.	° F.
t	*p*	*g p*	*v*	*V*	*1/v*	*1/V*	*h*	*L*	*H*	*s*	*S*	*t*
−20	7.50	14.6*	0.02610	11.00	38.35	0.0952	−9.0	165.5	156.5	−0.020	0.356	−20
−15	8.30	13.0*	.02620	9.90	38.15	.101	−7.0	164.0	157.0	−0.015	.354	−15
−10	9.28	11.0*	.02635	8.91	37.95	.112	−4.5	163.0	158.5	−0.010	.353	−10
− 5	10.4	8.8*	.02645	7.99	37.80	.125	−2.5	162.0	159.5	−0.005	.351	− 5
0	11.6	6.3*	0.02660	7.17	37.60	0.139	0.0	160.5	160.5	0.000	0.350	0
+ 1	11.9	5.7*	.02663	7.02	37.55	.142	0.5	160.5	161.0	.001	.350	+ 1
2	12.2	5.1*	.02667	6.87	37.50	.146	+1.0	160.0	161.0	.002	.350	2
3	12.5	4.5*	.02670	6.72	37.46	.149	1.5	160.0	161.5	.003	.350	3
4	12.8	4.0*	.02672	6.57	37.43	.152	2.0	159.5	161.5	.004	.350	4
5‡	**13.1**	3.3*	**0.02675**	**6.41**	**37.40**	**0.156**	**2.5**	**159.5**	**162.0**	**0.005**	**0.348**	**5‡**
6	13.3	2.7*	.02677	6.28	37.35	.159	3.0	159.0	162.0	.006	.349	6
7	13.6	2.1*	.02680	6.15	37.31	.163	3.5	159.0	162.5	.007	.349	7
8	13.9	1.5*	.02683	6.02	37.27	.166	4.0	158.5	162.5	.009	.349	8
9	14.2	0.9*	.02686	5.88	37.23	.170	4.5	158.5	163.0	.010	.349	9
10	14.6	0.2*	0.02690	5.75	37.20	0.174	5.0	158.5	163.5	0.011	0.348	10
11	14.8	0.1	.02692	5.65	37.15	.177	5.5	158.0	163.5	.012	.348	11
12	15.2	0.5	.02695	5.52	37.11	.181	6.0	158.0	164.0	.013	.348	12
13	15.6	0.9	.02698	5.41	37.07	.185	6.5	157.5	164.0	.014	.348	13
14	15.9	1.2	.02700	5.30	37.04	.190	7.0	157.5	164.5	.015	.348	14
15	16.3	1.6	0.02705	5.18	37.00	0.193	7.5	157.0	164.5	0.016	0.347	15
16	16.7	2.0	.02706	5.08	36.96	.197	8.0	157.0	165.0	.017	.347	16
17	17.0	2.3	.02709	4.98	36.92	.201	8.5	156.5	165.0	.018	.347	17
18	17.4	2.7	.02711	4.88	36.88	.205	9.0	156.5	165.5	.019	.347	18
19	17.8	3.1	.02714	4.78	36.84	.209	9.5	156.0	165.5	.020	.347	19

*20	18.2	3.5	0.02717	4.68	36.80	0.214	10.0	156.0	166.0	0.021	0.346	20
21	18.6	3.9	.02720	4.59	36.76	.218	10.5	155.5	166.0	.022	.346	21
22	19.0	4.3	.02723	4.50	36.72	.222	11.0	155.5	166.5	.023	.346	22
23	19.4	4.7	.02726	4.41	36.68	.227	11.5	155.5	167.0	.025	.346	23
24	19.8	5.1	.02729	4.32	36.64	.231	12.5	154.5	167.0	.026	.346	24
25	20.2	5.5	0.02730	4.24	36.60	0.236	13.0	154.5	167.5	0.027	0.346	25
26	20.6	5.9	.02735	4.15	36.56	.241	13.5	154.0	167.5	.028	.346	26
27	21.0	6.3	.02737	4.07	36.53	.246	14.0	154.0	168.0	.029	.346	27
28	21.5	6.8	.02741	4.00	36.48	.250	14.5	154.0	168.5	.030	.346	28
29	21.9	7.2	.02744	3.93	36.44	.254	15.0	153.5	168.5	.031	.346	29
30	22.3	7.6	0.02745	3.86	36.40	0.259	15.5	153.5	169.0	0.032	0.346	30
35	24.6	9.9	.02760	3.52	36.20	.284	18.0	152.5	170.5	.038	.346	35
40	26.9	12.2	.02780	3.22	36.00	.311	21.0	151.0	172.0	.044	.346	40
45	29.5	14.8	.02795	2.96	35.80	.338	24.0	150.0	174.0	.049	.346	45
50	32.5	17.8	.02810	2.71	35.60	.369	27.0	148.5	175.5	.055	.346	50
55	35.5	20.8	0.02825	2.49	35.40	0.402	30.0	147.5	177.5	0.061	0.347	55
60	38.7	24.0	.02840	2.28	35.20	.439	33.0	146.0	179.0	.067	.348	60
65	42.2	27.5	.02855	2.10	35.00	.476	36.5	144.5	181.0	.073	.349	65
70	45.8	31.1	.02875	1.94	34.80	.515	39.5	143.5	183.0	.079	.350	70
75	49.7	35.0	.02890	1.79	34.60	.559	43.0	142.0	185.0	.086	.351	75
80	53.9	39.2	0.02910	1.66	34.35	0.602	46.5	140.5	187.0	0.092	0.352	80
85	58.6	43.9	.02930	1.54	34.10	.649	50.0	139.0	189.0	.098	.353	85
86‡	59.5	44.8	.02935	1.52	34.10	.658	50.5	139.0	189.5	.099	.354	86‡
90	63.3	48.6	.02950	1.42	33.90	.704	53.5	137.5	191.0	.105	.356	90
95	68.4	53.7	.02965	1.32	33.70	.758	57.5	136.0	193.5	.112	.358	95
100	73.7	59.0	0.02990	1.23	33.45	0.813	61.0	134.5	195.5	0.118	0.359	100
105	79.3	64.6	.03005	1.14	33.25	.877	65.0	133.0	198.0	.125	.360	105
110	85.1	70.4	.03030	1.07	33.00	.935	69.0	131.0	200.0	.132	.362	110
115	91.4	76.7	.03050	0.990	32.80	1.01	73.0	129.5	202.5	.139	.364	115
120	98.0	83.3	.03075	.926	32.50	1.08	77.0	127.5	204.5	.147	.367	120
125	104.8	90.1	0.03095	0.867	32.30	1.15	81.5	126.0	207.5	0.154	0.369	125
130	112.0	97.3	.03125	.811	32.00	1.23	86.0	124.0	210.0	.161	.371	130
135	119.3	104.6	.03145	.760	31.80	1.32	90.5	122.0	212.5	.169	.375	135
140	126.8	112.1	.03175	.716	31.50	1.40	95.0	120.5	215.5	.176	.377	140

* Inches of Mercury below one standard atmosphere (29.82 in. = 14,696 lbs./sq. in. abs.)

‡Standard Ton Temperatures.

ETHANE

TABLE 2A-29. PROPERTIES OF ETHANE

Chemical symbol	C_2H_6
Weight of liquid, lbs. per cu. ft. at 32° F.	25.4
Boiling point, °F.	−128
Freezing point, °F.	−277.6
Latent heat of vaporization, Btu.	234
Conditions at critical point:	
Temperature, °F.	90.04
Pressure, lbs. abs.	720
Evaporator pressure at 5° F., lbs. abs.	236
Condensing pressure at 86° F., lbs. abs.	681
Toxicity, Underwriters Grouping.	5
Inflammability	Inflammable

TABLE 2A-30. PROPERTIES OF ETHANE

(Arranged from table by Linde Air Products Company by permission)

Temp., °F.	Pressure, lbs./in.^{2}		Volume, ft.^{3}/lb.		Density, lbs./ft.^{3}		Enthalpy of Vaporization Btu per lb.
	Abs.	Gage	Liquid	Vapor	Liquid	Vapor	
−150	7.0	15.6 *	0.02849	16.7	35.10	0.060	242
−140	9.7	10.1 *	0.02888	12.1	34.63	0.083	238
−130	13.2	3.0 *	.02924	8.85	34.20	.113	235
−120	18.2	3.5	.02961	6.89	33.77	.145	231
−110	24.8	10.1	.03001	5.27	33.32	.190	227
−100	32.4	17.7	.0305	4.13	32.8	.242	224
− 90	41.0	26.3	0.0309	3.23	32.4	0.310	220
− 80	51.2	36.5	.0313	2.56	31.9	.390	216
− 70	63.0	48.3	.0318	2.10	31.5	.477	212
− 60	78.2	63.5	.0322	1.75	31.0	.570	208
− 50	95.9	81.2	.0327	1.50	30.5	.666	204
− 40	114.5	99.8	0.0333	1.28	30.0	0.780	199
− 30	135.0	120.3	.0339	1.13	29.5	0.875	194
− 20	159.5	144.8	.0345	.976	28.9	1.03	190
− 10	187	172.3	.0353	.819	28.3	1.22	185
− 0	219	204.3	.0361	.689	27.7	1.45	179
5	236	221.3	0.0365	0.629	27.4	1.59	176
10	254	239.3	.0570	.581	27.0	1.72	174
20	292	277.3	.0579	.495	26.3	2.02	168
30	335	320.3	.0390	.422	25.6	2.37	162
40	383	368.3	.0403	.360	24.8	2.78	155
50	428	413	0.0417	0.305	24.0	3.28	146
60	481	466	.0435	.256	23.0	3.90	136
70	543	528	.0461	.214	21.7	4.67	124
80	625	610	.0508	.163	19.7	6.14	107
86	681	666	.0569	.122	17.8	8.2	70
89.8	718	703	.0775	.0775	12.9	12.9	0

* Inches of mercury below one standard atmosphere (29.82 in. = 14,696 lbs./in.^{2} abs.)

PROPANE

TABLE 2A-31. PROPERTIES OF PROPANE

Chemical symbol	C_3H_8
Weight of liquid, lbs. per cu. ft. at 32° F	33.2
Boiling point, °F	−44
Freezing point, °F	−309.8
Conditions at critical point:	
Temperature, °F	204
Pressure, lbs. abs	661.5
Latent heat of vaporization, atmospheric, Btu	182.6
Evaporator pressure at 5° F., lbs. abs	42.1
Condensing pressure at 86° F., lbs. abs	155.3
Toxicity, Underwriters Grouping	5
Inflammability	Inflammable

TABLE 2A-32. PROPERTIES OF SATURATED PROPANE

(*Compiled by Linde Air Products Co.*
Arranged by A.S.R.E. Published by permission)

Temp.	Pressure		Volume		Density		Enthalpy Above 0° F.			Entropy From 0° F		Temp.
° F.	Abs. lb./in.²	Gage lb./in.²	Liquid ft³/lb.	Vapor ft.³/lb	Liquid lb./ft³	Vapor lb./ft.³	Liquid Btu./lb.	Latent Btu./lb.	Vapor Btu./lb.	Liquid Btu./lb.°F.	Vapor Btu./lb.°F	° F.
t	p	gp	v	V	$1/v$	$1/V$	h	L	H	s	S	t
−75	6.37	17.0*	0.02660	14.5	37.59	0.0690	−39.5	190.5	151.0	−0.092	0.404	−75
−70	7.37	14.9*	.02674	12.9	37.40	.0775	−37.0	189.5	152.5	−0.086	.400	−70
−65	8.48	12.7*	.02688	11.3	37.20	.0885	−34.5	188.0	153.5	−0.080	.397	−65
−60	9.72	10.1*	.02703	9.93	37.00	.111	−32.0	187.0	155.0	−0.074	.393	−60
−55	11.1	7.3*	.02717	8.70	36.80	.115	−29.0	185.5	156.5	−0.067	.391	−55
−50	12.6	4.3*	0.02732	7.74	36.60	0.129	−26.5	184.5	158.0	−0.061	0.389	−50
−45	14.4	0.6*	.02748	6.89	36.39	.145	−24.0	183.0	159.0	−0.055	.386	−45
−40	16.2	1.5	.02763	6.13	36.19	.163	−21.5	181.5	160.0	−0.049	.384	−40
−35	18.1	3.4	.02779	5.51	35.99	.181	−19.0	180.0	161.0	−0.042	.382	−35
−30	20.3	5.6	.02795	4.93	35.78	.203	−16.0	179.0	163.0	−0.036	.380	−30
−25	22.7	8.0	0.02811	4.46	35.58	0.224	−13.5	177.5	164.0	−0.030	0.378	−25
−20	25.4	10.7	.02827	4.00	35.37	.250	−11.0	176.0	165.0	−0.024	.377	−20
−15	28.3	13.6	.02844	3.60	35.16	.278	− 8.0	175.0	167.0	−0.018	.375	−15
−10	31.4	16.7	.02860	3.26	34.96	.307	− 5.5	173.5	168.0	−0.012	.374	−10
− 5	34.7	20.0	.02878	2.97	34.75	.337	− 2.5	172.0	169.5	−0.006	.372	− 5
0	38.2	23.5	0.02895	2.71	34.54	0.369	0.0	170.5	170.5	0.000	0.371	0
+ 1	39.0	24.3	.02899	2.66	34.49	.376	0.5	170.5	171.0	.001	.371	+ 1
2	39.7	25.0	.02903	2.61	34.45	.383	1.0	170.5	171.5	.002	.371	2
3	40.5	25.8	.02906	2.57	34.41	.389	1.5	170.0	171.5	.003	.371	3
4	41.3	26.6	.02910	2.52	34.37	.396	2.0	170.0	172.0	.004	.371	4
5‡	**42.1**	**27.4**	**0.02913**	**2.48**	**34.33**	**0.403**	**+ 3.0**	**169.5**	**172.0**	**+0.006**	**0.370**	**5‡**
6	42.9	28.2	.02916	2.43	34.29	.411	3.5	169.0	172.5	.007	.370	6
7	43.7	29.0	.02920	2.39	34.25	.418	4.0	168.5	172.5	.008	.370	7
8	44.5	29.8	.02924	2.35	34.20	.426	4.5	168.5	173.0	.009	.370	8
9	45.3	30.6	.02927	2.31	34.16	.433	5.0	168.0	173.0	.010	.370	9

10	46.1	31.4	0.02931	2.27	34.12	0.441	5.5	168.0	173.5	0.012	0.370	**10**
11	47.0	32.3	.02935	2.23	34.07	.448	6.0	168.0	174.0	.013	.370	11
12	47.9	33.2	.02939	2.19	34.03	.456	6.5	167.5	174.0	.014	.370	12
13	48.8	34.1	.02943	2.15	33.98	.465	7.5	167.0	174.5	.015	.370	13
14	49.7	35.0	.02946	2.11	33.94	.474	8.0	166.5	174.5	.016	.370	14
15	50.6	35.9	0.02950	2.07	33.90	0.483	8.5	166.5	175.0	0.018	0.369	**15**
16	51.6	36.9	.02954	2.04	33.85	.491	9.0	166.0	175.0	.019	.369	16
17	52.5	37.8	.02959	2.00	33.80	.500	9.5	166.0	175.5	.020	.369	17
18	53.5	38.8	.02963	1.97	33.75	.509	10.0	165.5	175.5	.021	.369	18
19	54.5	39.8	.02966	1.93	33.71	.518	10.5	165.5	176.0	.022	.369	19
20	55.5	40.3	0.02970	1.90	33.67	0.526	11.0	165.0	176.0	0.024	0.368	**20**
25	60.9	46.2	.02991	1.74	33.43	.575	14.0	163.5	177.5	.030	.368	25
30	66.3	51.6	.03012	1.60	33.20	.625	17.0	162.0	179.0	.035	.366	30
35	72.0	57.3	.03033	1.48	32.97	.676	20.0	160.5	180.5	.041	.366	35
40	78.0	63.3	.03055	1.37	32.73	.730	23.0	159.0	182.0	.047	.366	40
45	84.6	69.9	0.03078	1.27	32.49	0.787	26.0	157.5	183.5	0.053	0.365	**45**
50	91.8	77.1	.03102	1.18	32.24	.847	29.0	156.0	185.0	.059	.365	50
55	99.3	84.6	.03125	1.10	32.00	.909	32.0	154.5	186.5	.065	.365	55
60	107.1	92.4	.03150	1.01	31.75	.990	35.0	153.0	188.0	.070	.364	60
65	115.4	100.7	.03174	0.945	31.50	1.06	38.0	151.5	189.5	.076	.364	65
70	124.0	109.3	0.03201	0.883	31.24	1.13	41.0	149.5	190.5	0.082	0.364	**70**
75	133.2	118.5	.03229	.825	30.97	1.21	44.0	148.0	192.0	.088	.364	75
80	142.8	128.1	.03257	.770	30.70	1.30	47.5	146.0	193.5	.093	.364	80
85	153.1	138.4	.03287	.722	30.42	1.39	50.5	144.5	195.0	.099	.364	85
86‡	**155.3**	**140.5**	**.03292**	**.717**	**30.38**	**1.40**	**51.0**	**144.0**	**195.0**	**.100**	**.364**	**86‡**
90	164.0	149.0	0.03317	0.673	30.15	1.49	54.0	142.5	196.5	0.105	0.364	**90**
95	175.0	160.0	.03348	.632	29.87	1.58	57.0	140.5	197.5	.111	.364	95
100	187.0	172.0	.03381	.591	29.58	1.69	60.5	138.5	199.0	.116	.363	100
105	200.0	185.0	.03416	.553	29.27	1.81	63.5	136.5	200.0	.122	.363	105
110	212.0	197.0	.03453	.520	28.96	1.92	67.0	134.0	201.0	.128	.363	110
115	226.0	211.0	0.03493	0.488	28.63	2.05	70.5	131.5	202.0	0.134	0.363	**115**
120	240.0	225.0	.03534	.459	28.30	2.18	73.5	129.0	202.5	.140	.363	**120**
125	254.0	239.0	.03575	.432	27.97	2.31	77.0	126.5	203.5	.145	.361	**125**

* Inches of Mercury below one standard atmosphere (29.82 in. = 14.696 lbs /sq. in. abs.)
‡ Standard Ton Temperatures

CARBON TETRACHLORIDE

TABLE 2A-33. PROPERTIES OF CARBON TETRACHLORIDE

Chemical symbol	CCl_4
Weight of liquid at 68° F., lbs. per cu. ft.	100
Boiling point at atmospheric, °F.	170.2
Freezing point at atmospheric, °F.	−9.5
Conditions at critical point:	
Critical temperature, °F.	541
Critical pressure, lbs. abs.	658
Latent heat of evaporation, atmospheric, Btu.	83
Suction pressure at 5° F., lbs. abs.	.24
Condensing pressure at 86° F., lbs. abs.	2.78
Toxicity, Underwriters Grouping	5
Inflammability	Noninflammable

TABLE 2A-34. CARBON TETRACHLORIDE SATURATED VAPOR TEMPERATURE TABLE

Temp., °F.	Absolute Pressure, lbs./in.^{2}	Volume, Vapor, ft.^{3}/lb.	Enthalpy Above 0 °F.			Entropy	
			Liquid, Btu./lb.	Latent, Btu./lb.	Vapor, Btu./lb.	Liquid, Btu./lb. °F.	Vapor, Btu./lb. °F.
t	p	v_g	h_f	h_{fg}	h_g	s_f	s_g
0	0.22	100.0	0.00	95.85	95.85	0.0000	0.2082
5	0.24	92.3	.95	95.50	96.45	.0019	.2077
10	0.31	85.0	1.90	95.19	96.09	.0040	.2070
20	0.46	69.5	3.80	94.45	98.25	.0084	.2055
30	0.60	53.0	5.70	93.70	99.40	.0121	.2040
40	0.84	40.0	7.60	93.20	100.80	.0152	.2022
50	1.10	30.1	9.55	92.60	102.15	.0185	.2005
60	1.42	24.0	11.70	92.20	103.90	.0220	.1990
70	1.85	19.5	13.62	91.40	105.02	.0254	.1980
80	2.40	16.0	16.00	90.07	106.07	.0290	.1970
86	2.78	14.2	17.20	90.04	107.24	.0310	.1960
90	3.12	13.0	18.00	90.02	108.02	.0320	.1955
100	4.00	10.0	20.00	89.40	109.40	.0357	.1950
110	4.89	8.5	21.00	89.10	110.10	.0392	.1945
120	5.95	7.5	24.60	87.90	112.50	.0430	.1940
130	7.20	6.3	27.30	87.10	114.40	.0462	.1945
140	8.65	4.8	29.40	86.30	115.70	.0490	.1930

CHLOROFORM

TABLE 2A-35. PROPERTIES OF CHLOROFORM (TRICHLOROMETHANE)

Chemical symbol	$CHCl_3$
Weight of liquid at 68° F., lbs. per cu. ft.	127.5
Boiling point at atmospheric, °F.	142
Freezing point at atmospheric, °F.	−82
Conditions at critical points:	
Temperature, °F.	500
Pressure, lbs. abs.	810
Latent heat of vaporization atmospheric, Btu.	109
Toxicity, Underwriters Grouping	3
Inflammability	Inflammable

TABLE 2A-36. TRICHLOROMETHANE SATURATED VAPOR TEMPERATURE TABLE

Temp., °F.	Absolute Pressure, lbs./in.^{2}	Volume, Vapor, ft.^{3}/lb.	Enthalpy Above 0° F.			Entropy	
			Liquid, Btu./lb.	Latent, Btu./lb.	Vapor, Btu./lb.	Liquid, Btu./lb. °F.	Vapor, Btu./lb. °F.
t	p	v_g	h_f	h_{fg}	h_g	s_f	s_g
0	0.738	55.61	0.000	123.62	123.62	0.0000	0.2685
5	.773	52.92	1.115	123.15	124.26	.0024	.2676
10	.835	50.15	2.230	122.68	124.91	.0052	.2666
20	.966	44.26	4.460	121.72	126.18	.0098	.2641
30	1.400	38.28	6.690	120.72	127.41	.0140	.2618
40	1.411	31.57	8.920	119.80	128.72	.0183	.2588
50	1.930	23.51	11.15	118.80	129.95	.0224	.2564
60	2.609	18.44	13.38	117.85	131.23	.0263	.2538
70	3.286	14.37	15.61	116.90	132.51	.0300	.2514
80	4.188	11.47	17.84	115.90	133.74	.0346	.2498
86	4.832	10.50	19.17	115.38	134.55	.0360	.2475
90	5.249	9.32	20.07	114.90	134.97	.0372	.2462
100	6.533	7.46	22.30	113.95	136.25	.0405	.2440
110	8.118	6.25	24.53	113.0	137.53	.0438	.2418
120	9.954	5.19	26.76	112.00	138.76	.0470	.2395
130	12.178	4.32	28.99	111.05	140.04	.0500	.2375
140	14.429	4.07	31.22	110.00	141.22	.0528	.2353
150	17.416	3.12	33.45	109.04	142.49	.0554	.2335

DICHLOROETHYLENE (9 DIELINE)

TABLE 2A-37. PROPERTIES OF DICHLOROETHYLENE (DIELINE)

Chemical symbol	$C_2H_2Cl_2$
Weight of the liquid at 86° F., lbs. per cu. ft.	77.4
Boiling point at atmospheric, °F.	118
Freezing point at atmospheric, °F.	−70
Conditions at critical point:	
Temperature, °F.	470
Pressure, lbs. abs.	795
Latent heat of vaporization at 5° F., Btu.	136.1
Suction pressure at 5° F., lbs. abs.	.82
Condensing pressure at 86° F., lbs. abs	6.92
Toxicity, Underwriters Grouping.	4
Inflammability	Inflammable

TABLE 2A-38. PROPERTIES OF SATURATED DICHLOROETHYLENE

Temp., °F.	Absolute Pressure, lbs./in.²	Volume, Vapor ft.³/lb.	Enthalpy Above 0° F.			Entropy	
			Liquid, Btu/lb.	Latent, Btu/lb.	Vapor, Btu/lb.	Liquid, Btu/lb. °F.	Vapor, Btu/lb. °F.
t	p	v_g	h_f	h_{fg}	h_g	s_f	s_g
0	.693	73.2[illegible]	0.0	136.3	136.3	0.0000	0.2962
5	.820	61[illegible]	[illegible].4	136.2	137.6	.0029	.2961
10	.942	54[illegible]	[illegible].7	136.0	138.7	.0057	.2957
20	1.30	41[illegible]	[illegible]4	135.7	141.1	.0113	.2960
30	1.71	31[illegible]	[illegible]1	135.4	143.5	.0162	.2928
40	2.24	24.[illegible]	[illegible].8	135.0	145.8	.0220	.2932
50	2.87	19.3	13.5	134.7	144.2	.0265	.2917
60	3.76	15.1	16.2	134.2	150.9	.0313	.2903
70	4.78	12.0	18.9	133.9	152.8	.0357	.2877
80	6.03	9.7	21.6	133.6	155.2	.0405	.2885
86	6.92	8.5	23.1	133.4	156.5	.0425	.2875
90	7.59	7.8	24.3	133.3	157.6	.0445	.2871
100	9.37	6.42	27.0	133.0	160.0	.0483	.2863
110	11.47	5.32	29.7	132.6	162.3	.0521	.2821
120	14.09	4.38	32.4	132.3	164.7	.0559	.2842
130	17.15	3.64	35.1	132.0	167.1	.0595	.2830

ETHYL CHLORIDE

TABLE 2A-39. PROPERTIES OF ETHYL CHLORIDE

Chemical symbol	C_2H_5Cl
Boiling point, atmospheric, °F.	55.6
Freezing point, °F.	−217.7
Latent heat of vaporization, atmospheric, Btu.	168.6
Conditions at critical point:	
Temperature, °F.	361
Pressure, lbs. abs.	784
Evaporator pressure at 5° F., lbs. abs.	4.65
Condensing pressure at 86° F., lbs. abs.	27.1
Toxicity, Underwriters Grouping	4
Inflammability	Inflammable

TABLE 2A-40. PROPERTIES OF ETHYL CHLORIDE

(Data arranged by A.S.R.E. Published by permission)

Tem.	Pressure		Volume		Density		Enthalpy Above − 32° F.			Entropy From − 32°F.		
°F. t	Abs. lb./in.² p	Gage lb./in.² gp	Liquid ft.³/lb. v	Vapor ft.³/lb. V	Liquid lb./ft.³ $1/v$	Vapor lb./ft.³ $1/V$	Liquid Btu./lb. h	Latent Btu./lb. L	Vapor Btu./lb. H	Liquid Btu./lb.°F. s	Evap. Btu./lb.°F. L/T	Vapor Btu./lb.°F. S
−22	2.20	−12.5	0.01657	34.4	60.35	0.0291	−23.1	181.3	158.2	−0.0497	0.4139	0.3642
−13	2.85	−11.85	.01669	26.95	59.92	.0371	−19.2	179.9	160.7	− .0410	.4025	.3615
− 4	3.66	−11.04	.01682	21.33	59.45	.0469	−15.4	178.5	163.1	− .0324	.3915	.3591
+‡5	4.65	−10.05	.01695	17.06	59.00	.0586	−11.6	177.0	165.4	− .0241	.3807	.3566
14	5.85	− 8.85	.01708	13.77	58.55	.0726	− 7.7	175.5	167.8	− .0159	.3702	.3543
23	7.28	− 7.42	0.01721	11.21	58.10	0 0892	− 3.8	174.0	170.2	−0.0079	0.3602	0.3523
32	8.99	− 5.71	.01735	9.21	57.64	.1086	0.0	172.5	172.5	.0000	.3506	.3506
41	11.01	− 3.69	.01749	7.62	57.18	.1311	+ 3.8	170.9	174.7	+0.0077	.3411	.3488
50	13.37	− 1.33	.01763	6.36	56.72	.1573	7.7	169.3	177.0	.0154	.3320	.3475
59	16.11	+ 1.41	.01777	5.34	56.27	.1873	11.6	167.7	179.3	.0228	.3231	.3459
68	19.29	4.50	0.01792	4.51	55.80	0.2215	15.4	166.0	181.4	0 0302	0.3144	0.3446
77	22.94	8.24	.01807	3.84	55.34	.2604	19.2	164.3	183 5	.0374	.3059	.3433
‡86	27.10	12.40	.01822	3.29	54.88	.3043	23.1	162.6	185.7	.0445	.2978	.3423
95	31.82	17.12	.01838	2.83	54.41	.3536	26.9	160.8	187.7	.0515	.2897	.3412
104	37.17	22.47	0.01854	2.44	53.94	0.4090	30 8	159.0	189.9	0.0583	0.2819	0.3402
113	43.16	28.46	.01870	2.13	53.47	.4704	34.6	157.2	191 8	.0651	.2743	.3394
122	49.88	35.18	.01887	1.86	53.00	.5382	38.5	155.3	193.8	.0718	.2668	.3386
131	57.36	42.66	.01904	1.63	52.52	.6135	42.3	153.3	195.6	.0783	.2594	.3377

ETHYLAMINE

TABLE 2A-41. PROPERTIES OF ETHYLAMINE

Chemical symbol	$C_2H_5NH_2$
Weight of the liquid at 68° F., lbs. per cu. ft.	43
Boiling point at atmospheric, °F.	61.6
Freezing point at atmospheric, °F.	−115
Latent heat of evaporation at atmospheric, Btu.	260
Conditions at critical point:	
Temperature, °F.	362
Pressure, lbs. abs.	815
Inflammability	Inflammable

TABLE 2A-42. PROPERTIES OF SATURATED ETHYLAMINE

Temp., °F. t	Absolute Pressure, lbs./in.² p	Enthalpy Above −40° F.		
		Liquid, Btu/lb. h	Latent, Btu/lb. h_{fg}	Vapor, Btu/lb. h_g
−40	.74	0	290.93	290.93
−20	1.518	12.15	285.35	297.50
0	2.91	25.07	279.42	294.49
5	3.342	27.61	278.43	306.04
10	4.156	30.74	276.94	307.68
20	5.194	36.02	273.94	309.96
30	6.750	43.33	270.84	314.17
40	8.750	49.54	267.66	317.20
50	11.165	56.21	263.59	319.80
60	14.140	62.82	261.06	323.88
70	17.696	69.54	257.62	327.16
80	21.92	76.37	254.10	330.47
86	24.72	80.50	251.96	332.46
90	26.89	83.13	250 65	333.78
100	32.64	90.63	246.25	336.88
110	39.38	97.66	242.63	340.29
120	47.07	104.56	239.21	343.77

METHYLAMINE

TABLE 2A-43. PROPERTIES OF METHYLAMINE

Chemical symbol	CH_3NH_2
Weight of liquid at 68° F., lbs. per cu. ft.	31
Boiling point temperature, °F.	19
Freezing point, °F.	−134.5
Conditions at critical point:	
Temperature, °F.	314
Pressure, lbs. abs.	1082
Latent heat at atmospheric, Btu	360.7
Inflammability	Inflammable

TABLE 2A-44. PROPERTIES OF SATURATED METHYLAMINE

Temp., °F.	Absolute Pressure, lbs./in.²	Enthalpy Above −40° F.		
		Liquid, Btu/lb.	Latent, Btu/lb.	Vapor, Btu/lb.
t	p	h	h_{fg}	h_g
−40	2.53	0	381.7	381.7
−20	4.88	14.1	375.0	389.1
0	9.22	28.7	367.9	396.6
5	10.03	32.6	365.9	398.5
10	11.50	36.1	363.9	400.0
20	14.88	43.3	360.0	403.3
30	18.98	50.9	355.1	406.0
40	23.99	58.4	351.4	409.8
50	29.87	66.1	347.0	413.1
60	37.08	73.9	342.6	416.3
70	45.31	81.8	337.6	419.4
80	55.20	89.7	332.8	422.5
86	61.53	94.5	325.9	424.4
90	65.57	97.8	327.9	425.7
100	77.47	105.0	323.7	428.7
110	93.49	114.4	317.3	431.7
120	110.61	122.9	311.7	434.6

METHYL FORMATE

TABLE 2A–45. PROPERTIES OF METHYL FORMATE

Chemical symbol	$C_2H_4O_2$
Weight of liquid at 68° F., lbs. per cu. ft.	61.8
Boiling point at atmospheric, °F.	89.2
Freezing point at atmospheric, °F.	−147.5
Latent heat of vaporization, atmospheric, °F.	205
Conditions at critical point:	
Temperature, °F.	417.2
Pressure, lbs. abs.	607
Suction pressure at 5° F., lbs. abs.	175
Condensing pressure at 86° F., lbs. abs.	13.81
Toxicity, Underwriters Grouping	3
Inflammability	Inflammable

TABLE 2A–46. PROPERTIES OF SATURATED METHYL FORMATE

Temp., °F.	Absolute Pressure, lb./in.^{2}	Volume Vapor, ft.^{3}/lb.	Enthalpy Above 0° F.			Entropy	
			Liquid, Btu/lb.	Latent, Btu/lb.	Vapor, Btu/lb.	Liquid, Btu/lb. °F.	Vapor, Btu/lb. °F.
t	p	v_g	h_f	h_{fg}	h_g	s_f	s_g
0	1.50	54.0	0	232.5	232.5	0.0000	0.5055
5	1.74	46.7	2.6	231.0	233.6	.0055	.5029
10	2.02	40.5	5.2	229.4	234.6	.0109	.4994
20	2.70	31.0	10.3	226.3	236.6	.0219	.4934
30	3.56	24.0	15.5	223.2	238.7	.0327	.4887
40	4.66	18.9	20.6	220.1	240.7	0.0432	0.4837
50	6.02	15.1	25.8	217.0	242.8	.0530	.4787
60	7.61	12.0	30.9	213.9	244.8	.0633	.4748
70	9.67	9.80	36.1	210.7	246.8	.0735	.4710
80	12.07	7.98	41.2	207.6	248.8	.0825	.4670
86	13.81	6.92	44.3	205.8	250.1	0.0882	0.4655
90	14.93	6.51	46.4	204.5	250.9	.0920	.4640
100	18.26	5.38	51.5	201.4	252.9	.1015	.4615
110	23.07	4.46	56.7	198.3	255.0	.1106	.4586
120	27.24	3.74	61.8	195.2	257.0	.1192	.4559
130	32.67	3.17	67.0	192.0	259.0	0.1280	0.4535
140	38.41	2.65	72.1	188.9	261.0	.1375	.4525
150	46.15	2.29	77.3	185.7	263.0	.1450	.4493
160	54.01	1.94	82.4	182.6	265.0	.1540	.4485
170	62.85	1.66	87.6	179.7	267.3	.1625	.4475

METHYLENE CHLORIDE

TABLE 2A-47. PROPERTIES OF METHYLENE CHLORIDE (CARRENE 1)

Chemical symbol	CH_2Cl_2
Weight of liquid at 68° F., lbs. per cu. ft.	84
Boiling point at atmospheric, °F.	103.6
Freezing point, atmospheric, °F.	−142
Conditions at critical point:	
Temperature, °F.	421
Pressure, lbs. abs.	708
Latent heat of vaporization at 5° F., Btu.	162
Suction pressure at 5° F., lbs. abs.	1.28
Condensing pressure at 86° F., lbs. abs.	10.07
Toxicity, Underwriters Grouping	4
Inflammability	Inflammable

TABLE 2A-48. PROPERTIES OF SATURATED METHYLENE CHLORIDE

			Enthalpy Above 0° F.			Entropy	
Temp., °F. t	Absolute Pressure, lbs./in.^{2} p	Volume, Vapor, ft.^{3}/lb. v_g	Liquid, Btu./lb. h_f	Latent, Btu./lb. h_{fg}	Vapor, Btu./lb. h_g	Liquid, Btu./lb. °F. s_f	Vapor, Btu./lb. °F. s_g
0	.98	58.65	0.00	163.16	163.16	0.0000	0.3546
5	1.28	49.90	1.70	162.10	163.80	.0046	.3535
10	1.38	42.55	3.40	161.00	164.40	.0072	.3502
20	1.92	31.40	6.80	158.80	165.60	.0151	.3461
30	2.56	23.90	10.20	156.69	166.89	.0222	.3425
40	3.38	18.60	13.60	154.39	167.99	0.0285	0.3377
50	4.36	14.68	17.00	152.04	169.04	.0350	.3335
60	5.52	11.68	20.40	149.71	170.11	.0410	.3292
70	7.07	9.38	23.80	147.20	171.00	.0466	.3246
80	8.81	7.50	27.20	144.82	172.02	.0520	.3202
86	10.07	6.68	29.75	143.28	173.07	0.0550	0.3180
90	10.87	6.20	30.60	142.26	172.86	.0570	.3160
100	13.25	5.14	34.00	139.65	173.65	.0620	.3113
110	16.40	4.31	37.40	136.98	174.38	.0652	.3058
120	19.20	3.65	40.80	134.20	175.00	.0714	.3031
130	22.69	3.10	44.20	131.30	175.50	0.0756	0.2983
140	26.79	2.69	47.60	128.40	176.00	.0795	.2935

TRICHLOROETHYLENE (TRIELINE)

TABLE 2A–49. PROPERTIES OF TRICHLOROETHYLENE (TRIELINE)

Chemical symbol	C_2HCl_3
Weight of liquid at 68° F., lbs. per cu. ft.	90.1
Boiling point at atmospheric, °F.	188
Freezing point at atmospheric, °F.	−126
Conditions at critical point:	
Temperature, °F.	520
Pressure, lbs. per sq. in. abs.	730
Latent heat of evaporation at atmosphere, Btu.	100
Suction pressure at 5° F., lbs. abs.	.156
Condensing pressure, lbs. abs.	1.72
Toxicity, Underwriters Grouping	4

TABLE 2A–50. PROPERTIES OF TRICHLOROETHYLENE SATURATED VAPOR

Temp., °F.	Absolute Pressure, lbs./in.^{2}	Volume, Vapor, ft.^{3}/lb.	Enthalpy Above 0° F.			Entropy	
			Liquid, Btu./lb.	Latent, Btu./lb.	Vapor, Btu./lb.	Liquid, Btu./lb. °F.	Vapor, Btu./lb. °F.
t	p	v_g	h_f	h_{fg}	h_g	s_f	s_g
0	.150	261.3	0.0	112.60	112.60	0.0000	0.2451
5	.156	230.5	0.91	112.50	113.41	.0025	.2461
10	.194	197.6	1.86	112.32	114.18	.0039	.2433
20	.252	153.3	3.90	112.10	116.00	.0081	.2429
30	.352	114.5	6.12	111.80	117.92	.0127	.2411
40	.492	85.8	8.42	111.41	119.83	.0178	.2412
50	.672	63.2	11.10	111.05	122.15	.0227	.2406
60	.900	47.53	13.80	110.63	124.43	.0278	.2404
70	1.20	36.00	16.80	110.22	127.02	.0324	.2407
80	1.56	28.00	19.84	109.78	129.62	.0374	.2410
86	1.72	24.63	21.67	109.50	131.13	.0410	.2423
90	1.98	22.46	23.22	109.32	132.54	.0428	.2418
100	2.45	18.54	26.60	108.81	135.41	.0480	.2426
110	3.15	14.62	29.92	108.30	137.22	.0530	.2432
120	3.98	11.73	33.60	107.78	141.38	.0581	.2441
130	5.05	9.20	37.70	107.20	144.96	.0632	.2450
140	6.31	7.70	42.00	106.57	148.57	.0680	.2459
150	7.69	6.55	45.00	105.90	150.90	.0738	.2475

SECTION IIB

NOMOGRAPHS FOR REFRIGERANTS

Use of Nomographs

A set of two nomographs for each of the refrigerants, ammonia, dichlorodifluoromethane and methyl chloride is included in this section. With their aid, many problems, which consume much time and labor, may be quickly and easily solved. The method of using is best illustrated by the solution of specific problems.

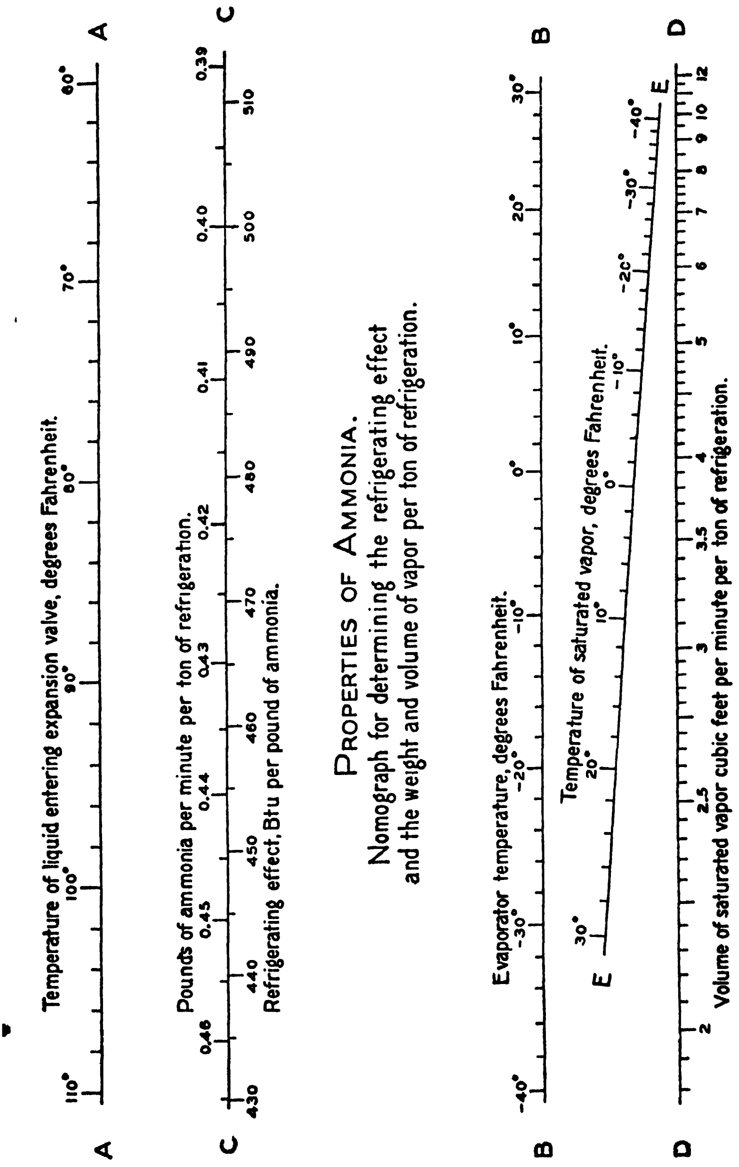
Problem 1. A 10-ton ammonia system operates with the evaporator at 10° F. and the liquid entering the expansion valve at 90°. It is desired to compute the weight of refrigerant circulated per minute, the refrigerating effect per pound of ammonia and the volume of saturated vapor flowing per minute.

Solution. For this problem use the chart entitled "Nomograph for Determining Refrigerating Effect and Weight and Volume of Vapor Per Ton of Refrigeration." On Scale *A* locate 90°, the temperature of the liquid entering the expansion valve and on Scale *B* locate 10°, the evaporator temperature. Connect these two points with a straight line and at its intersection with Scale *C* read, refrigerating effect 472 Btu per pound of ammonia and 0.424 lbs. of ammonia per minute per ton of refrigeration. Since the capacity of the system is 10 tons it is necessary to circulate 10 × 0.424 = 4.24 lbs. per min.

Now connect the point of intersection on Scale *C* by means of a straight line with 10° on Scale *E*, the temperature of saturated vapor in the evaporator. Read at the intersection of this line on Scale *D*, 3.1 cu. ft. per min. per ton of refrigeration. As this is a 10-ton system, the total vapor flowing per minute is 10 × 3.1 = 31 cu. ft. per min. Similar problems involving dichlorodifluoromethane (Freon 12) or methyl chloride systems may be solved in the same manner by the use of the proper charts.

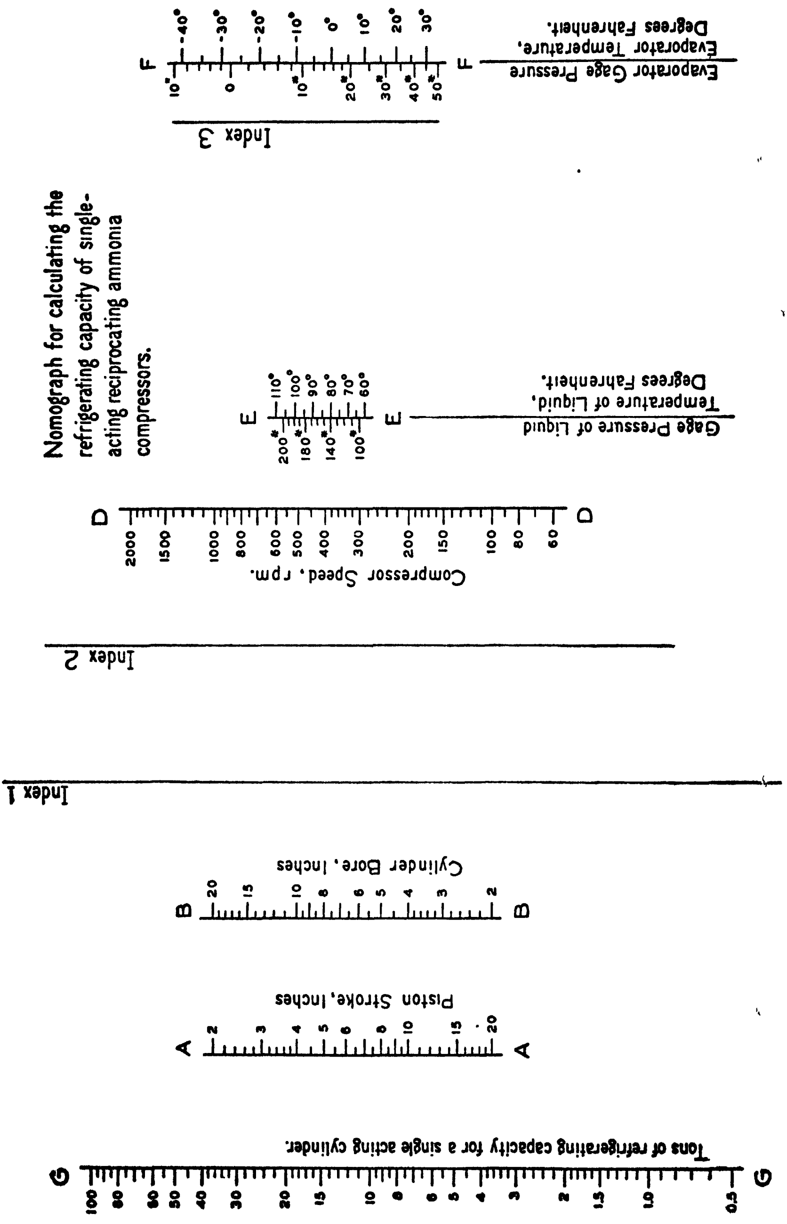
Problem 2. An 8 in. x 10 in. single acting single cylinder Freon 12 compressor operates at 250 rpm, with the evaporator held at 0° F. and the condenser at 88° F. Compute the capacity of this machine in tons of refrigeration.

Solution. For this problem use the chart entitled "Nomograph for Calculating the Capacity of Single-acting Reciprocating Compressors." Locate on Scale *A* the 8-in. bore and on Scale *B* the 10-in. stroke; lay a straight edge through these two points and note its intersection with Index 1. Now locate 250 rpm on Scale *D*, lay a straight edge through this point and the previously located intersection with Index 1, and note its intersection with Index 2 Then locate the evaporator temperature, 0° F. upon Scale *E* and the condenser temperature, 88° F., upon Scale *F*; connect these two points by a straight line and note its intersection with Index 3. Now connect the previously noted points on Index 2 and Index 3 with a straight line which is long enough to intersect Scale *G* and read the capacity 11.1 tons. It is to be borne in mind that this nomograph represents a perfect compressor, without leaks or valve losses. Hence, for an actual machine, the capacity will be approximately 70% of this figure or 7.8 tons.

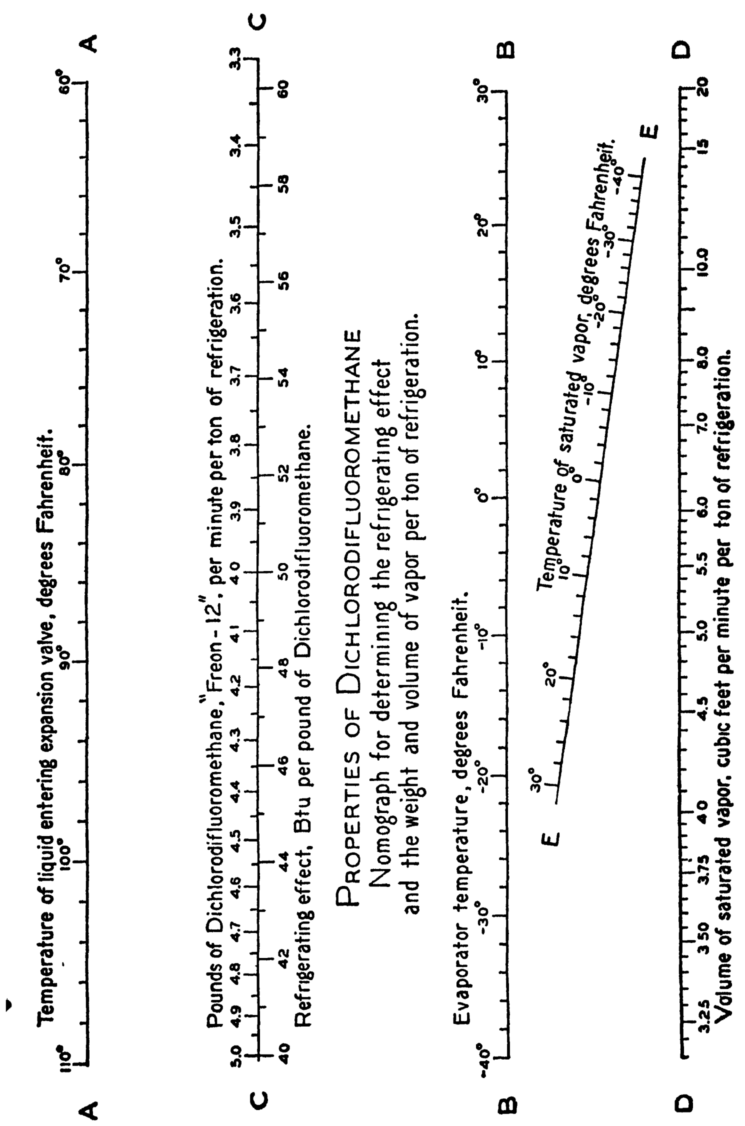


Properties of Ammonia.

Nomograph for determining the refrigerating effect and the weight and volume of vapor per ton of refrigeration.

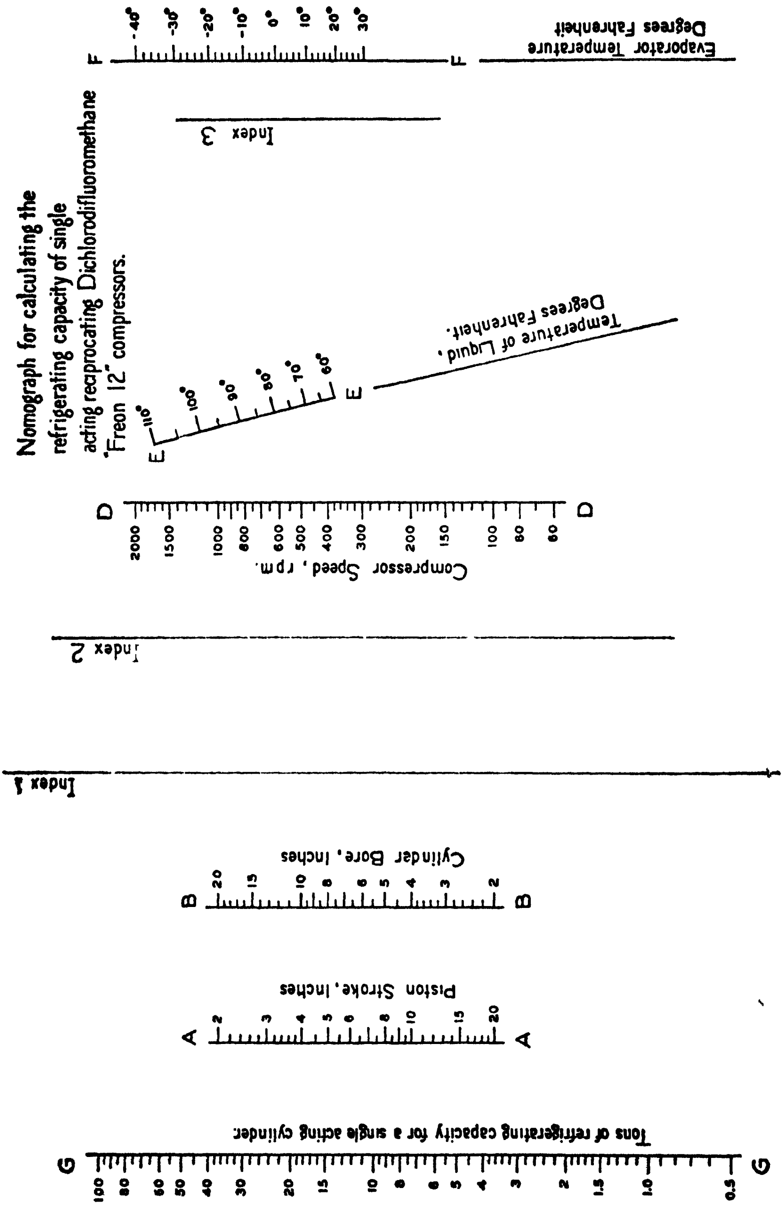


Nomograph for calculating the refrigerating capacity of single-acting reciprocating ammonia compressors.

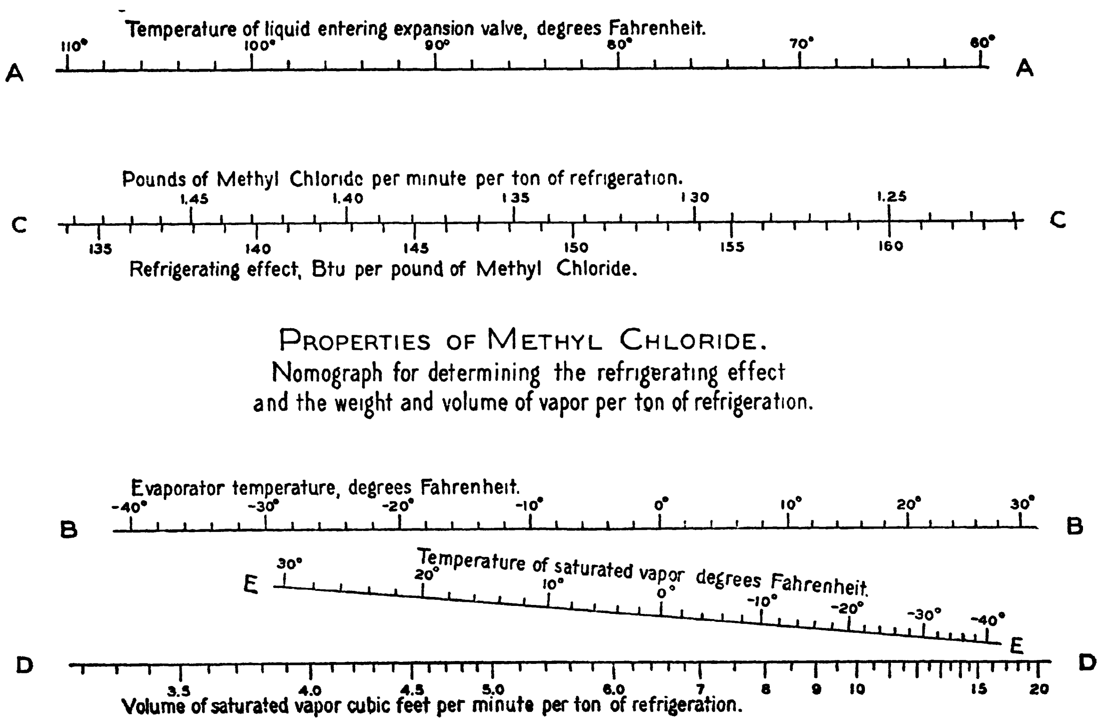


PROPERTIES OF DICHLORODIFLUOROMETHANE

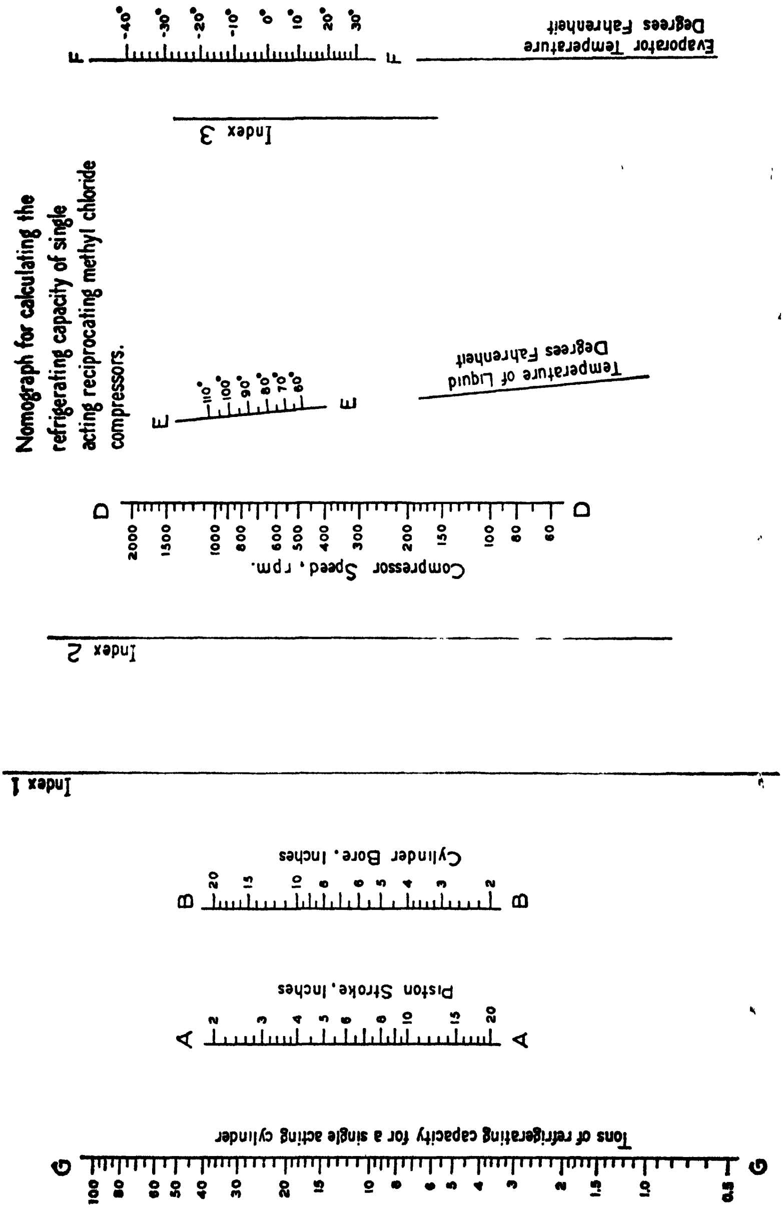
Nomograph for determining the refrigerating effect and the weight and volume of vapor per ton of refrigeration.



Nomograph for calculating the refrigerating capacity of single acting reciprocating Dichlorodifluoromethane "Freon 12" compressors.



PROPERTIES OF METHYL CHLORIDE.
Nomograph for determining the refrigerating effect and the weight and volume of vapor per ton of refrigeration.



Nomograph for calculating the refrigerating capacity of single acting reciprocating methyl chloride compressors.

SECTION III

RECIPROCATING COMPRESSORS

RECIPROCATING COMPRESSOR TYPES AVAILABLE

Three general types of reciprocating compressors are available:

1. Vertical single-acting compressors.
2. Horizontal double-acting compressors.
3. Compound compressors.

Practically all single-acting machines are vertical, and, vice versa, practically all vertical machines are single-acting.

Vertical Compressors. Vertical compressors are usually provided with a small clearance, sometimes not exceeding 0.020 in. in the large machines, and as low as 0.002 in. in the house service compressors. This small clearance makes imperative a false head or similar safety auxiliary that will act as a relief valve when the piston rises on its upward stroke. The safety feature is necessary since quantities of liquid may get into the cylinder and cause rupture with such small clearance space.

The false or safety head is an auxiliary cylinder head held in position by heavy coil springs. Normally, in the larger machines, this head never moves except when a slug of excess refrigerant or some other imcompressible foreign substance gets between the piston head and false cylinder head. When the incompressible material does get into the cylinder, the piston, on rising to its top position with its incompressible material, forces open the false head, and the material either passes on to the system or follows the piston head down on its suction stroke to come up again on the following stroke and again open the false head.

In some of the smaller and later designs of compressors, the false head also acts as the discharge valve and operates on every upward stroke. This makes possible an extremely small clearance space, and even should the piston strike the false head no serious effects would result.

The advantages of the single-acting vertical compressor are:

1. It requires less floor space than any horizontal unit of equal capacity and speed.

2. With vertical machines built with intake valves in the piston, the inertia of the machine assists greatly in opening and closing the valves promptly.

3. False cylinder-head construction permits the vertical compressor to operate with less clearance. Consequently, a greater volumetric efficiency is usually obtained than with horizontal machines.

4. Lubrication of the vertical pistons and piston rod is much better. Vertical pistons and rods do not ride on the cylinder or on the stuffing box gland, as horizontal machines necessarily must. This simplifies cylinder and rod lubrication.

5. The piston packing and gland of the vertical compressor are only exposed to intake pressures. This greatly reduces leakage and prevents the piston rod from being subjected to high-pressure temperatures. This results in more uniform operating conditions.

6. The design of horizontal steam cylinders driving vertical compressor units makes possible a maximum driving pressure from the steam cylinder upon the common crank pin when the vertical piston is doing its heaviest work in the extreme upward or discharge position.

Horizontal Compressors. Practically all horizontal compressors are double-acting machines. This requires a more difficult design than is necessary on vertical single-acting compressors.

When engine drive is used, the steam or gas and refrigerant cylinders may be arranged in tandem. When so arranged, the unit is usually referred to as a straight-line compressor.

Most horizontal engine-driven, single-stage compressors are connected up with the engine and refrigerant cylinders parallel to each other.

The principal argument in favor of horizontal compressors is the accessibility. The suction valves of the vertical machines, usually located in the piston head, are not readily accessible. In the ordinary horizontal designs, both the suction and discharge valves can be readily removed for adjustment or repair.

Other considerations in favor of the horizontal machines are the lower first cost for equal compressor tonnage installed, reduced machine vibration when operating under load, and less head room required for installing and operating the machine.

Compound Two-stage Compressors. Many engineers, even within the last decade, have pronounced the two-stage compound compressor a commercial impossibility. This was argued on the basis that no practical scheme could be devised to secure an equal division of the compressor load between the high-pressure and low-pressure sides in view of the fact that in winter the high-pressure cylinder discharge pressure would drop due to the low temperature of the condenser cooling water; whereas in summer the same cylinder may encounter very high pressures when 90° cooling water only was available.

Today, compound ammonia compressors are commercial and are successfully operated in many plants. In general, the designs are double-acting (either motor- or steam-driven), two-stage machines connected up with an intercooler. The vapor is first compressed in the low-pressure cylinder, then cooled in the intercooler to reduce the superheat, and compressed in the high-pressure cylinder to the pressure of the condenser.

Probably the two factors that have assisted most in making two-stage compression possible are, first, the introduction of the intercooler and, second, the development of better condenser systems to reduce the required discharge pressure on the high-pressure cylinder.

The advantages offered by the two-stage compressors are:

1. Reduction in the head pressure by auxiliary cooling.
2. Reduction of inlet heating as the refrigerant enters a cylinder that has not been heated excessively by the previous discharge.
3. Less leakage as the pressure differences are reduced.

SUPERHEATING IN COMPRESSION

With a general introduction of the available types of compressors, various factors must be considered that affect production. Superheating will be considered first.

In the study of refrigeration, it is necessary to distinguish between wet, dry and superheated refrigerants. Wet refrigerants contain finely divided particles of liquid. Dry refrigerant vapor is in a dry saturated state. Superheated refrigerants contain additional heat in excess of that characteristic of the vapor at that pressure.

When vapor is compressed, the temperature rises by virtue of the work done upon it. This heat of work raises the temperature of the vapor above its characteristic temperature for any given pressure. The vapor becomes superheated.

Four undesirable results are introduced by this superheating action. They are:

(1) Lubrication is more difficult.

(2) More work is brought on to the condenser.

(3) The volume of the vapor increases, causing more work for the compressor.

(4) High temperature has a tendency to break down some refrigerants.

On account of the introduction of these difficulties, attempts are made to reduce the superheating. Water-jacketing of the cylinders and intercooling between stages of compression, as a means of superheat reduction, will be considered.

Water Jacketing. Some arguments are presented against jacketing practice, based on the fact that only during the last part of each compression stroke is the temperature of the vapor high enough to be cooled by the average available cooling water. During the first part of the compression stroke the temperature of the vapor within the cylinder is much below the cooling water temperature, and the heat flow is from the jacket water to the vapor. During the last part of the compression stroke, the vapor is much warmer than the cooling water, due to the superheating of the vapor, and the heat flow is from the refrigerant to the cooling water

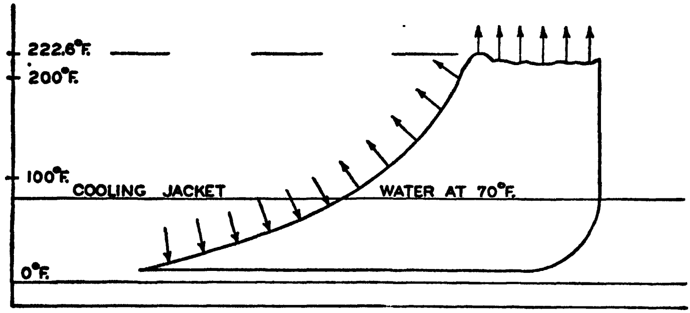


Fig. 3–1. Chart showing heat flow in typical ammonia compression cycle.

Figure 3–1 shows diagrammatically what can be expected of 70° F. jacket-cooling water in ammonia compression. The temperature scale to the left of the pressure-volume indicator card can be used for an approximate estimate of the rise of temperature in a typical compression machine. The compression line of the indicator card will, to some extent, represent this temperature rise.

Note that during the early part of the stroke the heat flow is from the cooling water to the ammonia, represented in Figure 3–1 by the arrows going toward the ammonia pressure-volume compression curve. In the upper part of the figure, the heat flows from the ammonia to the cooling water. The effective cooling will be the difference of heat absorbed by the water and the heat absorbed by the ammonia.

Intercooling. The argument offered against intercooling is similar to that offered against jacketing—that the low-pressure cylinder of a two-stage machine will not give temperatures high enough to make intercooling pay.

As emphasized, if the cooling water comes from either the jacket or the intercooler at a temperature higher than it enters, it is carrying away heat. In almost all installations, the cooling water is warmed up considerably in the jacket or intercooler of the compressor.

Some of the early two-stage compound compressors were provided with cooling water jackets on both the low-pressure and the high-pressure cylinders. This was a mistake when used on the low-pressure cylinder unless very cold water was available. During the major part of the stroke the gas inside of the cylinder was colder than the cooling water, and the cooling water had a negative instead of a positive effect.

Every British thermal unit separated from the refrigerant between compressor intake and expansion valve will produce that much more refrigeration in the cooler or evaporator. Heat carried away at the compressor is usually worth the investment in cooling water, and it relieves both the condenser and the compressor of considerable work, which in turn gives them increased capacity. But if the cooling water gives up heat instead of taking it up, the value of the cooling water is decidedly negative.

In tests which the writer has made on an Ingersoll Rand two-stage compressor operating with 56° F. spring water as the cooling medium in both the intercooler and multipass condenser, he found an inlet gas temperature of 36° F. on the low-pressure cylinder. Low-pressure compression was carried to 65 lbs. gage pressure at 130° F. The gas then passed through the intercooler and entered the high-pressure side at 105° and came out at 170° F. The pressure on the high side averaged 129 lbs. This machine was operated under varying conditions with cooling water up to

78° F. and has given no trouble in maintaining a balanced load between the two sides of the compressor.

Wet Compression. Since superheating is one of the undesirable results we meet in compression and, further, since a large quantity of heat is required to vaporize a small amount of liquid, a system of wet compression is sometimes used to prevent superheating.

By this system, small quantities of finely divided liquid are injected into the cylinder with the vapor and compressed with it. As the compressor pressure increases, the liquid and vapor temperature rises and tends to superheat the vapor. While liquid is present, it cannot superheat; but the surplus heat is utilized in vaporizing the liquid particles. The large amount of heat required to vaporize the particles, on account of their latent heat of vaporization requirements, prevents any appreciable superheating of the gas during compression. This results in the vapor being discharged from the compressor with a small amount of superheat, and the work on both the condenser and compressor is materially reduced, due to the absence of the superheat.

Oil Injection Compression. Excess cold oil is sometimes injected into the vapor as the piston starts on the compression stroke to reduce the superheat. The liquid oil absorbs a quantity of the superheat produced in the compression and is then separated out in a special oil separator before the compressed gas goes to the condenser.

Certain precautions are very necessary in this procedure. Only very light oils that will neither break down, saponify, nor vaporize under superheat temperature are necessary. Much of the trouble from noncondensable gases in refrigeration is caused by the reaction between low-grade oils and refrigerant.

Sleeve Valve Compressors. Sleeve valves have been recommended at intervals for the reciprocating compressor. One English manufacturer has successfully operated a rotary sleeve valve in industrial units. American manufacturers have not gone to this refinement since the present plate designs have kept pace with the allowable reciprocating piston speeds of modern compressors. However, the sleeve valve does open up new possibilities that will attract the inventive genius of both European and American designers.

Compression and System Cycles. Subsequent diagrams show the closed cycle of compression refrigeration. A closed system cycle is so termed when it pertains to the continuous flow of the refrigerant through the several processes that make up the system such as compression, condensation, expansion and evaporation of the refrigerant. A closed system infers that the refrigerant is pumped around in a circuit to be used over and over again.

A compression cycle may in itself be a closed cycle in that there are in succession the procedures of suction, compression, and gas discharge repeated over and over again in each subsequent revolution of the single-acting compressor. This cycle should not be confused with the closed cycle of the entire system.

The compression cycle can be represented by a pressure-volume diagram, a pressure-time diagram or a temperature-time diagram. These usually give the needed information on the compression cycle.

A temperature-entropy diagram (Figure 3–2) or a pressure-enthalpy diagram are better adapted to the closed system cycle. For clarity it will be assumed that a simple system is composed of the action of (1) the compressor, (2) the condenser, (3) the expantion valve and (4) the evaporator.

From the temperature-entropy diagram, the thermodynamic properties of the refrigerant are determined:

(1) Suction temperature and pressure of the refrigerant entering the compressor.

(2) State of the refrigerant entering the compressor, whether a mixture of liquid and vapor (wet mixture), all vapor with no superheat (dry or saturated vapor), or superheated vapor.

(3) Type of compression, whether constant entropy (adiabatic) or polytropic (any of an infinite number of processes, usually closely approximating the adiabatic). For all practical purposes the compression is assumed to be adiabatic; hence, the process follows a line of constant entropy.

(4) Temperature and pressure of the refrigerant leaving the compressor.

(5) Temperature and pressure of the refrigerant entering and leaving the condenser. It is to be remembered that this temperature is from 8° to 10° F. above the temperature of the cooling water entering the condenser.

(6) Degree of subcooling of the liquid refrigerant leaving the condenser. The greater the subcooling the more heat the refrigerant will pick up in the evaporator.

(7) Type of expansion of the refrigerant through the expansion valve, whether adiabatic or polytropic. Again, as in the compression process, the expansion process is assumed to be adiabatic

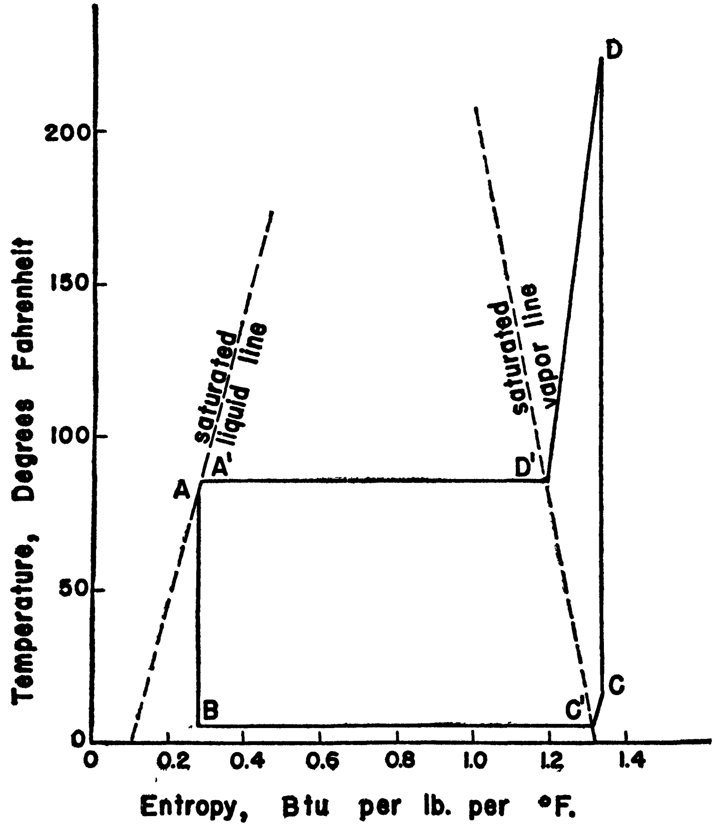


Fig. 3-2. Temperature-entropy diagram of refrigeration cycle. From *B* to *C* is the suction, from *C* to *D* is the compression stroke, from *D* to *A* is the condenser effect, and from *A* to *B* is the constant heat change through the expansion valve.

and on the diagram it follows a line of approximately constant entropy.

(8) Quality of the refrigerant entering the evaporator. In the expansion valve a small part of the liquid refrigerant flashes over into vapor. This small part of refrigerant has lost its capacity to

absorb its equivalent heat of vaporization from the space to be refrigerated unless the expansion valve itself is placed in that space. For practical purposes it is assumed that the refrigerant is all liquid as it enters the evaporator.

The above outline for a simple system may be further complicated (1) by the addition of a compound compressor using an intercooler, (2) by the addition of a superheat remover between the compressor and condenser or (3) by the addition of a flash vapor bypass from the expansion valve direct to the suction side of the compressor.

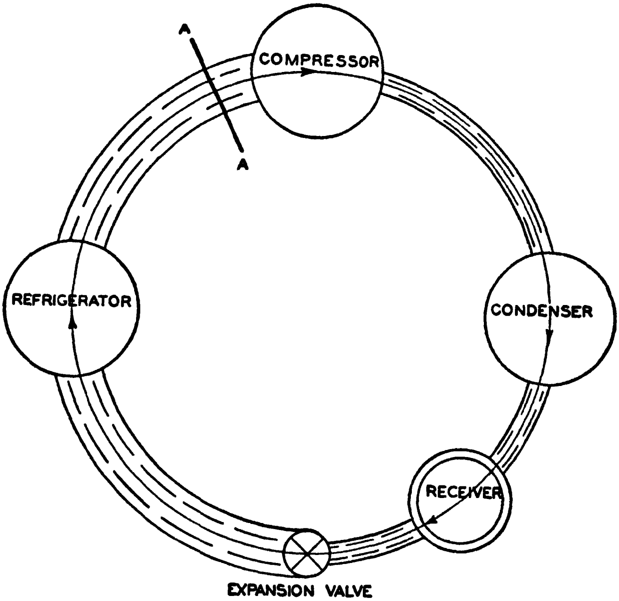


Fig. 3-3. Typical closed cycle for refrigerants. In working out the heat balance, each pound of the refrigerant must contain the same heat content each time it returns to the same point of the cycle. If this were not so, there would be an accumulation of heat or cold in the system.

For the closed system cycle for a refrigerant line *BC*, Figure 3-2, represents the suction and *CD* the compression. These two lines on a temperature-entropy diagram complete the entire closed cycle diagram of a pressure-volume graph, such as Figures 3-3, 3-4.

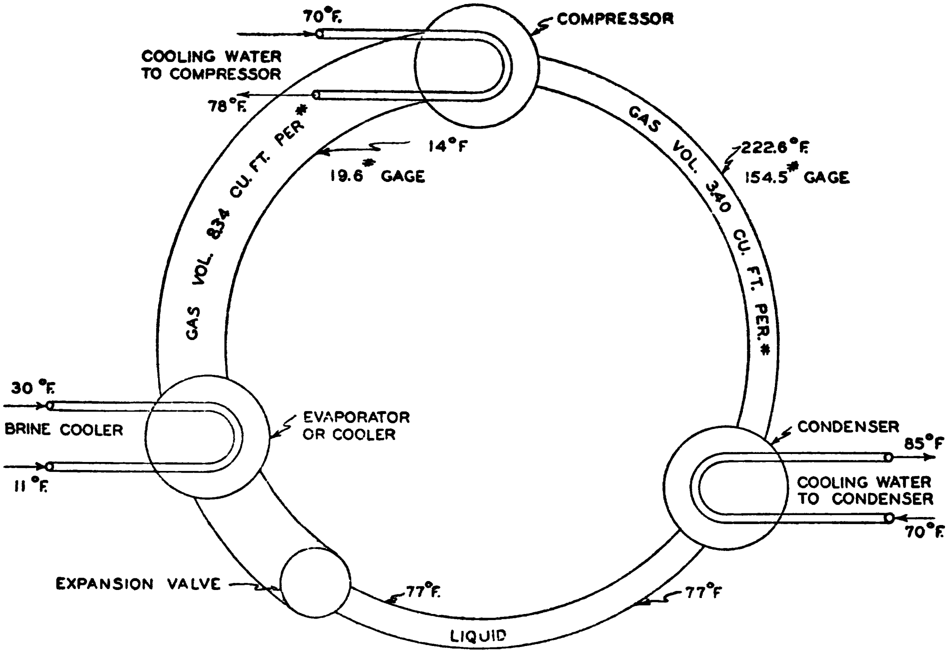


Fig. 3-4. Typical refrigerating closed cycle using ammonia with probable temperature and pressure relationships.

The indicator card is useful in determining the following thermodynamic properties and operating data not revealed by the temperature-entropy diagram:

(1) Clearance volume of the compressor.
(2) Displacement of the compressor.
(3) Discharge volume of the vapor leaving the compressor.
(4) Re-expansion volume of the refrigerant left in the cylinder after the discharge valve has closed.
(5) Suction and discharge pressures of the refrigerant.

Purpose of the Compressor. It is necessary to have a clear concept of why a refrigerant must be compressed and, paradoxically, heated so that it can remove heat from a space, or the products in a space, or both. One of the purposes of the compressor is to make it possible to use the refrigerant over and over again.

When the liquid refrigerant vaporizes in the process of absorbing heat from the space being cooled, the volume increases greatly. To be reused, it is more effective if it is made a liquid again. The most common method of liquefying the vapor is to pass it through a fluid-cooled condenser. The vapor, leaving a refrigerated space and entering the suction side of the compressor, is nearly always colder than the available cooling water or other liquid-cooling medium. Thus, to pass this vapor directly into the liquid-cooled condenser would simply cause the cooling liquid to become colder and the refrigerant vapor to become warmer. Liquefaction would be impossible under these conditions. In order to be liquefied, the vapor must enter the condenser at a higher temperature than the condenser cooling medium. No matter what the temperature of the cooling medium may be, if it is colder than the saturation temperature of the vapor and there is sufficient condenser surface, the vapor will condense. The purpose of the compressor, therefore, is to increase the vapor temperature above the cooling medium temperature with a corresponding increase in pressure. Fortunately, in increasing the temperature and pressure of the vapor the compressor also reduces the volume of the vapor and consequently reduces the size of the condenser surface required.

Limitations of Compressors. There are several types of commercial refrigerants. All of these do not have the same density, specific volume, latent heat of vaporization, or other thermodynamic properties. Also, some refrigerants have an adverse affect on specific metals whereas other refrigerants have no effect. In general, an ammonia compressor is designed for ammonia as the refrigerant, a Freon 12 compressor for Freon 12, etc. For safety and maximum efficiency of operation only the specific refrigerant should be employed for which the compressor is designed. Naturally, this applies to the entire system, including condenser, receiver, evaporator, valves, piping, fittings, and the like. Air compressors are not designed to be used as refrigerant compressors.

Factors Affecting the Selection of Compressor Size and Type. After the total load or number of Btu to be removed in a 24-hour period has been computed the design engineer next selects the compressors to handle the load requirements. For a large installation, such as a cold-storage plant, one might assume that a single large-capacity compressor would provide a more economical installation than several smaller compressors. Generally, this is not the case. Such an installation would be practical only when all the rooms in the plant are to be held at the same temperature, when the heat load to be removed from these rooms is maintained at a nearly constant value, and when the periods of shutdown are the same for all the rooms in the plant. Naturally, these conditions are difficult to realize in present-day cold-storage plants. The chilling room might be idle for several days or weeks. The single compressor would be operating at partial capacity to carry the rest of the plant. The partial capacity of a compressor is less efficient than the rated capacity. Likewise, the suction pressure from a blast freezer room or a brine cooler is less than the suction pressure from an egg storage room. These suction pressures must be all the same for a single compressor with one suction line. This means the higher of the suction pressures must be throttled through a pressure reducing valve to correspond with the lowest suction pressure. This method is wasteful of energy. An alternative is to use smaller capacity booster compressors to increase the low suction pressures to equal the highest suction pressure. Another alternative is to boost the lower suction pressures to an intermediate pressure and to throttle the higher pressures to the intermediate pressures.

The principal argument against a single compressor for an installation such as a cold-storage plant is the lack of a stand-by compressor in event of failure of the one large compressor.

By using several compressors the plant operation can be made more flexible and the over-all efficiency improved. In selecting the combination of sizes and types the purchaser should keep in mind the matter of repair parts. When all the compressors are of the same size and built by the same manufacturer, the spare parts to be kept on hand are reduced to a minimum.

It is recommended practice to install one stand-by compressor of a size equal to the largest compressor in the plant. This stand-by will then assume any load due to the shutdown of any one compressor in the plant.

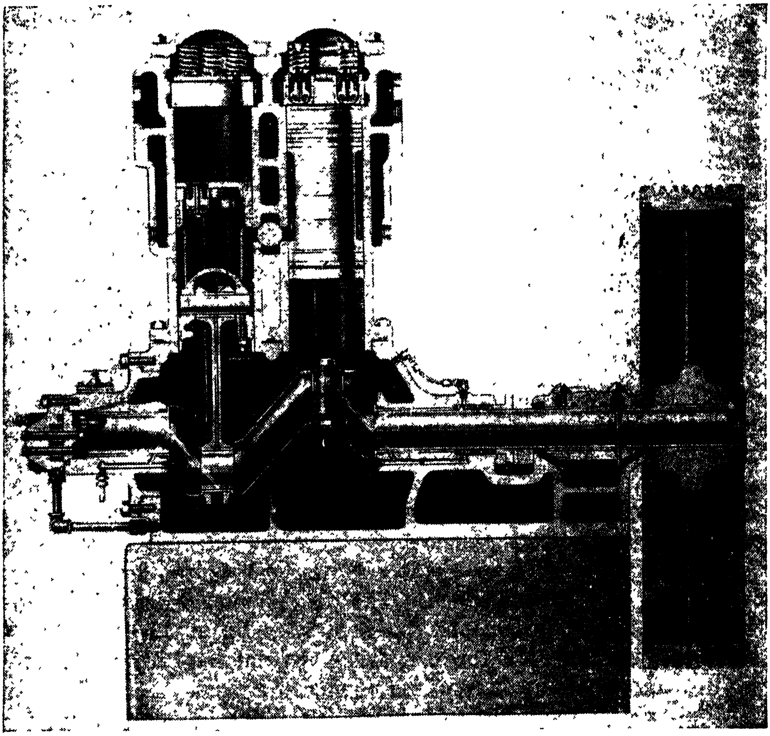


FIG. 3–5B. Cross section of ammonia compressor. (*Courtesy of York Corporation, York, Pa.*)

From the standpoint of maintenance and long life, a slow-speed compressor is preferable to a high-speed compressor. Also, a compressor in operation 12 to 16 hours per day will last longer than one operating 23 to 24 hours per day. In other words, large slow-speed compressors will last longer operating intermittently and give less maintainance trouble than small high-speed compressors of the same capacity operating continuously. To obtain intermittent operation of the several compressors in the plant they should have a capacity greater than that required of them. For example, if a ton of refrigerating effect is required and a one-ton capacity compressor is installed, the compressor must work 24 hours per day to remove the heat load. If a two-ton compressor is installed with automatic control device it will operate on and off automatically for a total of 12 hours per day.

Rating of a Compressor. The catalog rating of a compressor or of an entire condensing unit is often a confusing picture to the uninitiated. It may be given as tons, horsepower, or diameter of the bore times the length of stroke.

Tons of refrigeration is the rating of special interest to the plant owner. This rating gives a measure of how many cases of eggs can be cooled or how many blocks of ice can be manufactured every 24 hours, etc. This method of rating is not limited to tons of freezing refrigeration. The same rating is applied to the compressor when it is used in air-conditioning systems where the lowest temperature might be 85° F. Tons of refrigeration, in other words, indicates how many Btu the compressor is capable of removing in a specified period of time.

Horsepower rating, as distinguished from the horsepower rating of an automobile or Diesel engine, when used with a refrigerating compressor tells at a glance how large an internal combustion engine, steam engine, or electric motor is required to drive the compressor at its rated speed. The plant owner determined from the "ton" rating how many cases of eggs he could cool with a given compressor. He now can discover from the horsepower rating how much energy is required to cool the eggs.

Most manufacturers' catalogs list the ton and horsepower ratings of a compressor when operating at different suction temperatures and different condensing temperatures. This information tells the purchaser that for the same horsepower requirements he can get more refrigerating effect from his compressor when he uses it for air conditioning than when he uses it to maintain a lower temperature in a cold-storage room or a blast freezer. The information is of value in indicating the economy of low condensing temperatures and the cost of low evaporator temperatures.

From the curve plotted in Figure 3–6, for 105 lbs. gage condensing pressure, for example, to remove 12,000 Btu per hr. or one ton of refrigeration at 30° F. cold-room temperature and a corresponding 45 lbs. per sq. in. gage it will require 0.5 brake horsepower output from the compressor driving motor. If the temperature of this room is lowered to 0° F. and the corresponding 15 lbs. per sq. in. gage, it would require 1.20 brake horsepower to remove the 12,000 Btu per hr.

If the available cooling water is warmer, then the condensing pressure may rise to 145 lbs. per sq. in. gage. From the comparison of the two graphs it indicates that this increase of condensing temperature would result in an increase of the energy requirements for one ton of refrigeration of .25 horsepower.

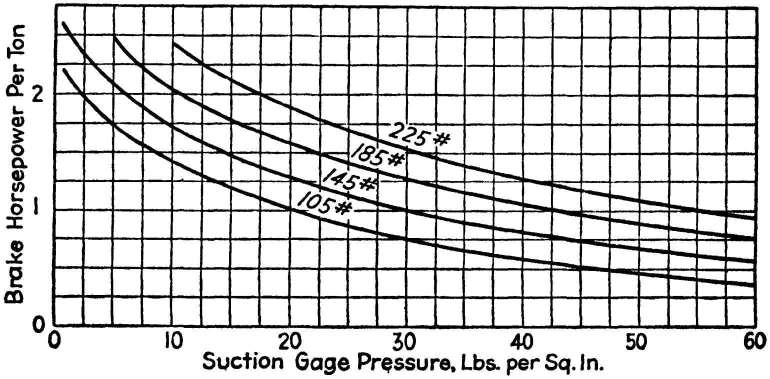


FIG. 3–6. Curves showing the brake horsepower per ton for different suction pressures for a typical 2-cylinder ammonia compressor. The pressures indicated on the curves are for different condensing pressures in pounds per square inch gage.

Compressors when rated by bore and stroke must specify the revolutions per minute. Most manufacturers' catalogs rate the compressor for some given speed. The increase of speed will give a corresponding increase in machine capacity, when the stroke and bore are kept constant. Most machines are given a speed rating that is the most economical compromise between first cost and machine life. A smaller faster machine might have equal capacity and cost less, but its life as a compressor would be greatly reduced.

COMPRESSOR CAPACITY CONTROLS

At the present time, many refrigeration compressors are operated by electric motors which run at approximately constant speed; thus it is necessary to make some provision for varying the rate at which vapor is pumped in order to accommodate variations in the refrigerating load. Throttling the suction line effectively reduces machine capacity but it is wasteful of energy and the discharge temperature of the compressed vapor is unnecessarily high.

There are three methods in use which result in reduction of capacity without seriously reducing the efficiency.

Suction Valve Lifting Unloader. Multi-cylinder compressors may have the capacity reduced by opening the suction valves of one or more cylinders. The power loss is limited to the very slight throttling effect as the gas passes alternately from the suction line into the cylinder and back. This method of control is inapplicable to reciprocating compressors having suction valves in the pistons but is suitable for machines with valves in the cylinder heads.

Bypass Unloader. In this type, an auxiliary passage provided with a valve connects the cylinder and the suction line. When this valve is open, gas merely surges into and out of the cylinder at suction pressure without any compression occurring. The net effect of this device is the same as lifting the suction valve from its seat. Control of the number of cylinders pumping gas may be secured by either manual or automatic devices.

Clearance Pockets. With the previously described devices, a cylinder pumps at full capacity or is completely ineffective. A clearance pocket permits a single cylinder to operate at some predetermined fraction of its normal capacity. The principle involves a closed chamber or pocket which is provided with a valved connection to the cylinder. Gas which is forced into the pocket during the compression stroke, re-expands during the suction stroke and prevents the entrance of a full charge into the cylinder. Multiple pockets may be fitted to each cylinder so that several steps of capacity reduction are secured by merely opening the valves connecting the pockets to the cylinder. The fraction of capacity secured by a clearance pocket is,

$$F = \frac{V_c}{V_p}\left[\left(\frac{P_2}{P_1}\right)^{\frac{1}{n}} - 1\right],$$

in which

F is the fraction of normal capacity,
V_c is volume of clearance,
V_p is piston displacement volume,
P_1 is absolute suction pressure,
P_2 is absolute discharge pressure,
n is exponent of polytropic compression.

SECTION IIIA

CENTRIFUGAL REFRIGERANT COMPRESSORS

In power production by reciprocating steam engines, one of the principal limiting factors of the economic usefulness of the engine is its inability to handle the very large volumes encountered at low pressures. For such large volumes steam turbines, on the other hand, are very well adapted.

In the compression of gases, likewise, large volumes of low-pressure gases encountered on the suction side of the machine are a limiting factor of the usefulness of either reciprocating or rotary compressors. In this field, the centrifugal compressor is the most usable.

Positive displacement compressors employ moving pistons or vanes to reduce the volume of the vapor and to move it from the low side to the high side. The reciprocating compressor uses a cylinder in which a closely fitted piston slides to displace the vapor, and valves are provided to insure that flow is in the desired direction. Rotary compressors employ revolving pistons or vanes as displacing elements and secure unidirectional flow of the vapor by means of valves or by the arrangement of the displacing members. The compression ratio is independent of the speed of the positive displacement unit and it will handle either light or dense vapors with equal effect.

The kinetic compressor imparts a high velocity to the vapor and converts this velocity energy to pressure head. Centrifugal machines are the most important example of this type of unit, although it seems probable that the axial flow turbo-compressor will soon prove itself suitable for refrigerating service. The ratio of compression is a function of compressor speed; hence, to secure operation at fixed evaporator and condenser temperatures the speed of the machine must be higher than the critical value at which pumping ceases. At constant speed the increase of pressure is a linear function of vapor density, thus for a given pressure range the higher the density of the vapor the lower may be the compressor speed.

The centrifugal compressor at present is limited to large installations. Dr. James R. Zwickl suggests that compressors smaller than 2500 cu. ft. per min. capacity are not practicable.

The experimental history of centrifugal compressors goes back to the work of Maurice Leblanc who, between 1910 and 1912, introduced laboratory units using carbon tetrachloride and water vapor. This work was followed by Willis Carrier who perfected centrifugal compressors for dichloroethylene and trichloroethylene in 1920 to 1925.

In Europe, the centrifugal compressor was developed in the Brown-Boveri plant of Switzerland for ammonia, ethyl bromide and ethyl chloride between 1925 and 1935.

During the past decade Carrier, York, Worthington, Trane, and Ingersoll Rand have successfully introduced units of the centrifugal type adapted mostly to the compression of Freon refrigerants and to water vapor.

Dr. Zwickl points out that the lower the vapor pressure of the refrigerant, the larger is the value of the cubic feet per minute per ton. On the basis of 2500 cu. ft. per min., centrifugal compressors of a minimum capacity of 60 tons of refrigeration are economically feasible for Freon 113, while with a refrigerant like ammonia, the minimum economic size of the machine would be 1400 to 1500 tons.

There are approximately 400,000 tons of centrifugal refrigeration installed in the world. This tonnage is divided over approximately 1100 installations. Thus the typical average installation is between 300 and 400 tons capacity. There are very few installations of less than 100 tons capacity.

Until 1932 most of these installations were built to use methylene chloride, trichloroethylene, dichloroethylene, ammonia, or water vapor. After 1932, the Freon refrigerants started taking their place in centrifugal installations and today a large number of the new installations use one of the Freon family as a refrigerant.

W. H. Carrier and R. W. Waterfill observed as early as 1924 that there existed a wide variation in the thermodynamic efficiencies of various refrigerants when used in centrifugal compressors.

Refrigerants that have been considered commercially adaptable to centrifugal compression are, in the order of their experimental introduction to the refrigeration trade, as follows: carbon tetrachloride, water vapor, dichloroethylene, trichloroethylene, ammonia, methylene chloride, ethyl bromide, ethyl chloride, Freon 11, Freon 12, and Freon 113.

Centrifugal compressors obtain their higher pressures by a multiple staging effect. As in centrifugal fans and pumps the pressure from the first stage is stepped up by each successive stage. The higher pressure refrigerants require a larger number of stages than a low-pressure refrigerant. Further the suction pressure of a centrifugal compressor system is largely preserved in the refrigeration cycle since there is relatively no closing of the circuit of circulated refrigerant in the centrifugal compressor cycle.

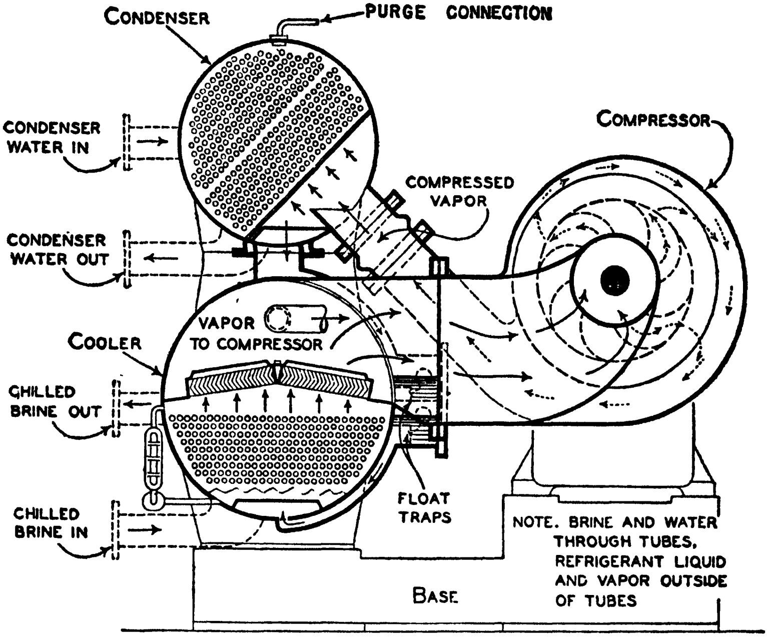


FIG. 3A-1. Diagrammatic drawing of Carrier centrifugal refrigerating machine. (*Published Courtesy Carrier Corporation.*)

Efficiency of Centrifugal Compression. For large installations, centrifugal compression can be expected to take over a large portion of the new refrigeration capacity purchased for air conditioning and related applications. The high efficiency which a typical centrifugal compressor maintains at low and high percentages of machine loading makes it most adaptable to the wide variations in cooling demands. A typical capacity-efficiency curve is given herewith (Figure 3a-2).

A further improvement in over-all refrigeration plant operating efficiency can be realized by virtue of the absence of lubricating oil in the refrigerant compressed by a centrifugal compressor. The carry-over of lubricating oil into the condensers and evaporators is not a problem in centrifugal compression, since no internal lubrication is necessary.

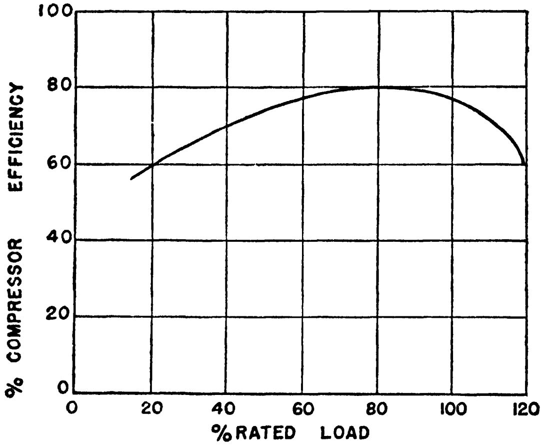


FIG. 3A–2. The typical centrifugal compressor operates at low ratings with good efficiency.

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TABLE 3A-1. ADAPTATION CHARACTERISTICS OF COMMON REFRIGERANTS AS APPLIED TO CENTRIFUGAL COMPRESSORS *

	At 5° Sat. Evaporation and 86° Sat. Condensing								At 40° Sat. Evaporation and 100° Sat. Condensing					
	Ammonia	Freon 12	Methyl Chloride	Sulfur Dioxide	Carbon Dioxide	Carrene No. 1 Methylene Chloride)	(Carrene No. 2) Freon 11	Carnot Cycle	Ammonia	Freon 12	(Carrene No. 2) Freon 11	Water	Carbon Dioxide †	Carnot Cycle
Gage pressure corresponding to sat. evap.	19.6	11.8	6.46	5 89″ Vac.	317.5	27.55″ Vac.	23 95″ Vac.	. ....	58.6	36.98	15 61″ Vac.	29.75″ Vac.	553.1	..... .
Gage pressure corresponding to sat. cond.	154.5	93.2	80.00	51.75	1028.3	8.35″ Vac.	3.58	....	197.2	116.9	8.90	28.07″ Vac.	1054.7	....
Specific volume of vapor at sat. evap	8.15	1.49	4.47	6.42	0.266	49.90	12.27	....	3.97	0.792	5.45	2438	0.1444	....
Latent heat of evaporation..	565.0	69.47	180.70	169.38	117.5	162.10	84.00	.. ...	536.2	65.7	81.2	1068.8	95.0	....
Liquid circulation (lb. per min. per ton)..... . ..	0.42	3.92	1.33	1.41	3.53	1.49	2.96	. ..	0.43	3.88	2.90	0.198	5.04	....
Theoretical displacement (ft. per min. per ton)	3.44	5.82	5.95	9.08	0.94	74 5	36.4	. .	1.70	3.07	15.8	482.0	0.727	....
Refrigerating effect (Btu per lb.).....	474.4	51.1	150.25	141.37	56.7	134.1	67.5	. .	467.8	51.6	68.8	1008.9	39.7	....
Compression ratio cond. pres. (lb. abs.)............ / Suc. pres. (lb. abs.)	4.93	4.07	4.48	5.62	3.14	8.59	6.24	......	2.89	2.54	3 36	7.78	1.885	....
Theoretical (hp. per ton).........	0.989	1.007	0.963	0.970	1.84	0.965	0.936	0.822	0.649	0.667	0.625	0.665	0.867	0.566
Coefficient of performance 200 / (Theoretical hp. × 42.4).........	4.77	4.69	4.90	4.86	2.56	4.89	5.04	5.74	7.28	7.07	7.55	7.08	5.45	8.34
Efficiency % Carnot cycle........	83.2	81.6	85.4	84.7	44.6	85.2	87.8	100.	87.3	84.9	90.9	85.0	52.0	100.0

* Published by permission of Carrier Corporation.

† For sat. evaporation at 40° F. and sat. condition at critical point = 87.8° F.

SECTION IIIB

JET COMPRESSORS

The application of the jet compressor to refrigerating machines has been limited entirely to systems which employ water as the refrigerant and steam as the power fluid. The jet pump itself contains no moving parts to wear or require adjustment. It is simple, rugged, compact and relatively light. However, the over-all efficiency is less than some other types of refrigeration compressors, and the characteristics of the refrigerant limits the application to temperatures above the freezing point of water, the refrigerant.

Figure 3b–1 illustrates the principles employed in the jet compressor. High-pressure steam flows through the nozzle *A* which converts a portion of its potential energy to the kinetic energy of the high velocity jet. An expanding nozzle is employed for the steam and other compressible fluids, whereas a converging nozzle is used for liquids, which are essentially incompressible.

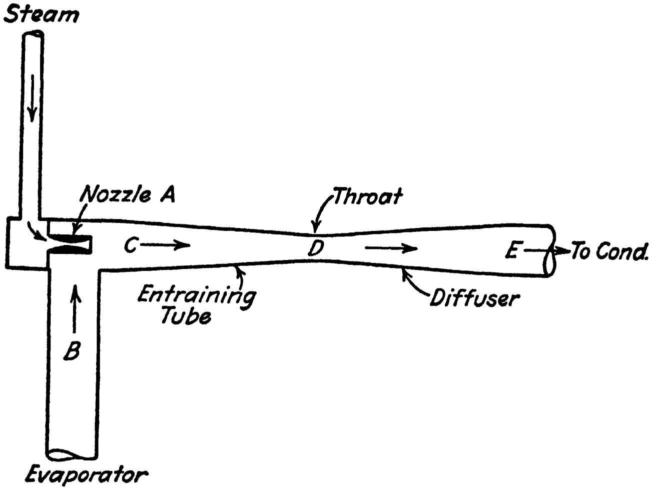


FIG. 3B–1.

The low-pressure fluid, which is to be compressed, enters through the suction connection *B* and passes to the entrainment chamber *C*, where it meets the high velocity jet issuing from the nozzle. A portion of the jet energy is transferred to the low-pressure fluid, increasing the kinetic energy, and the mixed fluids now pass through the throat *D* of the Venturi tube and into the diffuser section *E*, where the velocity is reduced and converted to pressure head.

Losses in jet compressors occur through fluid friction against the nozzle walls and in the Venturi throat and the diffuser section. The greatest loss of available energy is due to impact and eddies when the high velocity jet mixes with the relatively slow moving low pressure fluid.

Jet compressors are sometimes called thermo-compressors or steam jet vacuum ejectors. The principal accessories are (1) a high pressure system of steam nozzles, (2) a high vacuum flash chamber, (3) a booster compressor consisting of the combining chamber and the diffuser, (4) the condenser for the booster compressor, (5) an air ejector which usually includes an auxiliary pair of first and second stage condensers, and (6) the necessary circulating pumps for the condensers and for the refrigerated water.

The jet compressor is especially adapted to installations for air conditioning where the refrigerated medium need not be below 45 or 50° F. and where there is an abundance of high-pressure steam and cooling water.

Jet compressors have proved especially useful for railroad passenger train cooling, where the motive power is the steam locomotive. Steam locomotives are regularly designed to meet the steam requirements for winter heating of the entire train. This capacity of the locomotive boiler would be little used in the summer unless the air-conditioning load can be saddled onto it.

The adaptation of the thermo-compressor using this surplus steaming capacity of the locomotive for cooling in the warm months establishes some balance between summer and winter steam needs. Experiences with this type of air-conditioning installation in many parts of the northern section of the United States indicate that the steam consumption for summer cooling very often balances the winter needs for steam heating of passenger trains.

From a thermodynamic standpoint the jet compressor system of refrigeration is not highly efficient since it usually requires from 35 to 40 lbs. of live steam per hour to produce one ton of air-conditioning refrigeration at refrigerated water temperatures of 45 to 60° F. The condensers must be large since the temperatures and the amount of steam involved require 300 to 400% more heat dissipation than would be involved in mechanical compression.

Steam jet compressors work more economically at high steam pressures than low. Tests indicate that the amount of steam needed at 15 lbs. gage pressure may equal 70 lbs. per ton of refrigeration produced, whereas with between 100 and 200 lbs. gage pressure the same equipment would produce the same cooling with 35 to 40 lbs.

When steam ejector refrigeration is used for train cooling, the same radiators and radiator lines that are used for winter heating may be used for summer cooling. The refrigerated water is circulated by centrifugal pumps to the train system.

SECTION IV

CONDENSERS

General. The condenser is a very important unit in the refrigeration system and it may be said that, in general, it has received less than its deserved share of attention. The successful operation of a plant is entirely dependent on the efficiency of the condenser and increased capacity may often be obtained by slight changes in the condenser. Condensers may be divided into three general classes, based upon the method of cooling, and these, in turn, may be further subdivided, according to construction and operating details. Following are the divisions and subdivisions of condenser classes in outline form:

I. Water-cooled
    A. Submerged
    B. Double-pipe
    C. Shell-and-coil
    D. Shell-and-tube
    E. Atmospheric
        1. Single-pass
        2. Multipass

II. Evaporative
    A. Natural Air Circulation
        1. Atmospheric
        2. Atmospheric Bleeder
    B. Forced-air Circulation

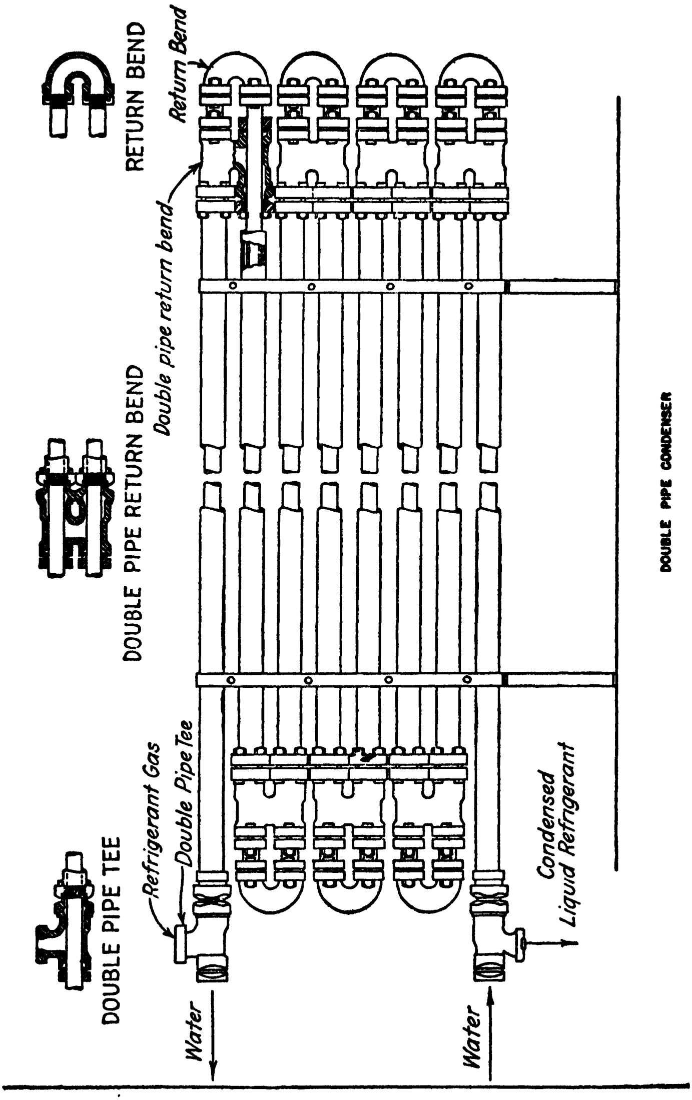
III. Air-cooled
    A. Finned-tube
    B. Automotive Radiator Type
    C. Plate type

WATER-COOLED CONDENSERS.

The submerged condenser is the simplest form of this type and in some cases may consist of a coil directly immersed in a pond or stream, although the usual form is a tank in which a coil of pipe is submerged. Refrigerant vapor enters the coil at the highest point, passes downward, and is discharged as liquid from the lowest point, while water enters the tank at the bottom and is discharged from the top. Thus counter-current operation is secured, since the coldest water meets the cool liquid refrigerant and the warmest water meets the incoming warm vapor. The over-all rate of heat transfer is rather low in this type of condenser, as the water circulation is very slow and air bubbles, which separate when water is warmed, collect upon the coil surface and act as insulation. Submerged condensers are bulky and difficult to clean. If the coil is located in a pond or stream, it must be disconnected and removed for cleaning; when located in a tank, draining is necessary to expose the coil surfaces. For condensing ammonia, the over-all heat transfer coefficient will approximate 25 Btu per sq. ft. per hr. per degree temperature difference between the cooling water and the refrigerant.

Double-pipe Condensers. The double-pipe condenser has been installed in a very large number of refrigerating plants and is highly regarded by operating engineers. In design (see Figure 4–1) it comprises two concentric tubes, connected by special return fittings to permit the circulation of water through the smaller inside pipe, while the refrigerant passes through the annular space between the inner and outer tubes. One great advantage of this type is that it may be constructed for any desired capacity from standard pipe and the return fittings which are a stock item. Standard screw fittings are made in a variety of sizes, although the most widely used double-pipe condensers have 1¼-in. inner pipes and 2-in. outer pipes. Construction involves merely cutting and threading the pipe and attaching the fittings.

The condenser is usually mounted in a stack of horizontal sections, one above the other and supported by upright standards which are clamped to the outer pipes. It may also be supported by walls or suspended from ceilings or trestles when space is at a premium. The ability to place the condenser in almost any location, together with the fact that increased cooling surface may be provided by merely adding more standard sections, gives this type of unit a very great flexibility of application. True counter-current operation makes the double-pipe condenser very economi-



DOUBLE PIPE CONDENSER

FIG. 4-1.

cal in the use of cooling water and the high water velocity results in an over-all heat transfer coefficient which compares favorably with any other type. The fact that water may be pumped directly through the double-pipe condenser to a cooling tower or elevated reservoir is of great value. In emergencies, the condensing capacity may be greatly increased by installing a spray pipe over each stand and a catch basin below, so that water may be delivered over the external surface of the refrigerant conduit.

Small water-cooled refrigerant condensing units frequently employ a special form of double-pipe condenser which is constructed of a pair of concentric metal tubes bent to the desired coil form. Tubes are welded or hard-soldered into continuous lengths to form the required surface before assembling and are provided with entrance and discharge fittings. Scale must be removed by acid solutions, since the condenser cannot be taken apart for cleaning.

Heat Transfer Coefficients of Double-pipe Condensers. Kratz, Macintire and Gould * carried out experiments on the condensation of ammonia vapor in a double-pipe counter-flow condenser consisting of twelve 1¼-in. water pipes inside 2 in. pipes, 18 ft. long. The heat transfer is reported only for the condensing section and it is concluded that the degree of superheat in the entering vapor does not materially affect the fraction of the surface which is exposed to saturated vapor. Data collected from these experiments yield the following mean heat transfer coefficients for the entire surface when the total rate of condensation is 0.032 lbs. of ammonia per min. per sq. ft. (see Table 4–1).

TABLE 4–1

Water Velocity, ft./min.	Over-all Heat Transfer Coefficient Btu/sq. ft./hr./°F.
180	250
270	330
360	370
450	380

---

* "Heat Transfer in Ammonia Condensers," Kratz, Macintire and Gould, *Bul. No. 171*, Univ. of Ill. Eng. Exp. Station.

Stewart and Holland * suggest the equation:

$$U = \frac{230 + \frac{v}{1.22}}{t_m}$$

for over-all heat transfer coefficients of double-pipe ammonia condensers, in which U is the over-all coefficient in Btu per hour per square foot per degree $F.$; v is the water velocity in feet per minute; and t_m is the mean temperature in degrees F. between the condensing refrigerant and the flowing water. It is stated that this expression includes both the desuperheating and the condensing effects.

The recommendations of one maker of double-pipe ammonia condensers having 1¼-in. inner and 2-in. outer pipes is listed below. It is to be noted that no water rates nor condensing pressures are specified and thus it must be assumed that these figures include generous allowances for adverse operating conditions.

TABLE 4–2. CAPACITY OF DOUBLE-PIPE AMMONIA CONDENSERS HAVING 1¼-IN. INNER AND 2-IN. OUTER PIPES

Number of Passes in Stand	Heat Exchange Surface		Tons Capacity at the Specified Temperature of Entering Water			
	Lineal Ft.	Square Ft.	55° F.	65° F.	75° F.	85° F.
4	73.0	31.7	3.9	3.6	3.1	2.5
6	109.5	47.6	5.9	5.4	4.6	3.7
8	146.0	63.4	7.8	7.2	6.2	4.9
10	182.5	79.3	9.8	9.0	7.7	6.2
12	219.0	95.2	11.8	10.8	9.3	7.4

Advantages of Double-pipe Condenser.

(1) It may operate on the counter-flow principle.

(2) It may be used wherever the water is to be further utilized without additional pumping.

(3) It may be located at any convenient point and there is no splash or overflow of water.

(4) The same type of unit may be used for brine or liquid coolers and thus the inventory of spare parts is greatly simplified.

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* Stewart and Holland, *Ref. Engineering*, Vol. 17, pp. 5–18, 1929.

Disadvantages.

(1) Cleaning is difficult and requires complete dismantling of the unit.

(2) Leaks are difficult to locate and repairs are hard to make.

The Shell-and-coil Condenser. This type is used to some extent in small- and medium-sized, water-cooled refrigerant condensing units. It comprises a water coil, which may be either a plain tube or extended surface, mounted inside a cylindrical shell that also serves as the liquid receiver. The chief disadvantage of this arrangement is the impossibility of cleaning the water passage by mechanical means and that scale deposits must be removed by acid solutions.

The atmospheric condenser may be used as a purely water-cooled unit but, in general, some heat is removed by vaporization; hence, this type is described under evaporative condensers.

The Shell-and-tube Condenser. The shell-and-tube condenser may be considered the logical evolution of the double-pipe condenser in which the refrigerant is placed in a large outer tube and the condensing water is run through a number of tubes inside the large tube or shell. In design, this piece of apparatus somewhat resembles the construction of a fire-tube boiler which has been fitted with suitable heads to direct the flow of water through the tubes. Refrigerant vapor is admitted to the upper part of the shell and condensed liquid is discharged from the lower part.

Two types of single-pass shell-and-tube condensers are made. In the vertical type (Figure 4–2), water is admitted to the tubes through special fittings, so that it flows by gravity in a film on the inner tube surfaces and is discharged to a catch basin at the base of the condenser. In some cases air is entrained by the water flow; thus, in addition to the sensible cooling effect of water, some evaporative cooling may be added. Since the tubes of this type are easily accessible for cleaning, even while operating, the vertical condenser is advantageously employed where scale-forming minerals are present in the cooling water.

In horizontal, single-pass condensers (Figure 4–3), the water movement is secured by pressure. To secure high heat transfer rates, it is necessary that the water velocity be fairly high; thus, the contact period between the coolant and the condenser tube is so short that only a small rise in the temperature of the water is produced unless the tubes are inordinately long. In order to obviate this disadvantage the multi-pass condenser has been

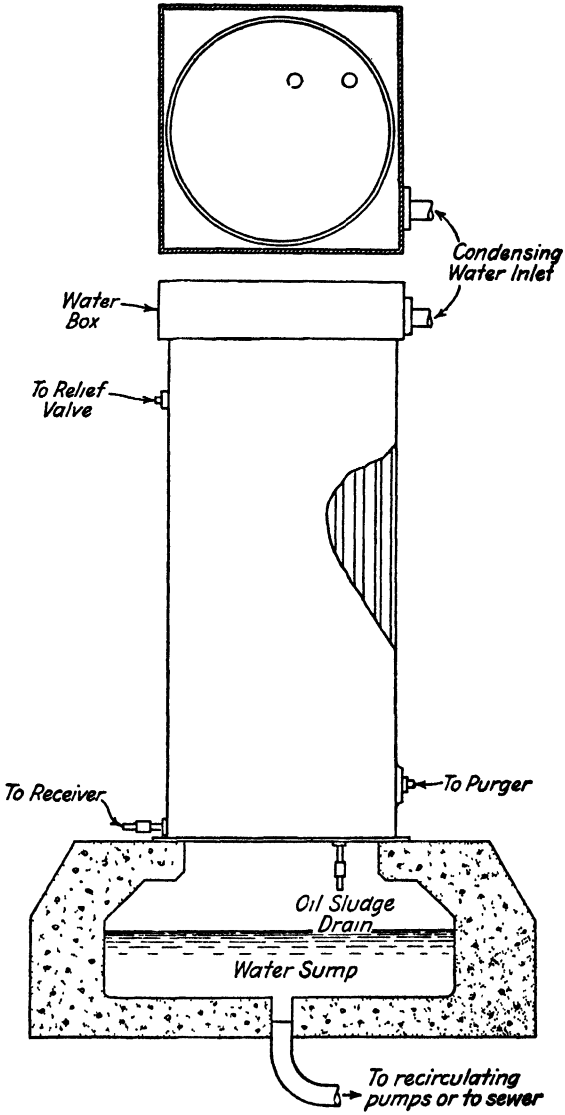

Condensing Water Inlet
Water Box
To Relief Valve
To Purger
To Receiver
Oil Sludge Drain
Water Sump
To recirculating pumps or to sewer

FIG. 4-2.

brought out. In this unit special heads are provided, so that the cooling liquid passes in one direction through one set of tubes and back again through another tube bank, repeating the reversal several times. Thus the effective length of travel of the water along the condensing surfaces may be made as great as desired and the temperature rise may be greatly increased over that occurring in a single-pass unit.

Shell-and-tube condensers are generally provided with removable heads to permit access to the water tubes for cleaning and inspection. Tubes are cleaned by brushing and scraping internally with long-handled tools or by means of power-driven cleaners such as are employed in steam boilers. Leaks in shell-and-tube condensers are difficult to detect during operation and may be present without any noticeable effect other than an unaccountable loss of refrigerant. Ammonia leaks may be detected by testing the discharged cooling water with Nessler's solution, which acquires a yellow to brown color in the presence of this refrigerant. No simple tests are known to detect the presence of other commonly used refrigerants in condensing water.

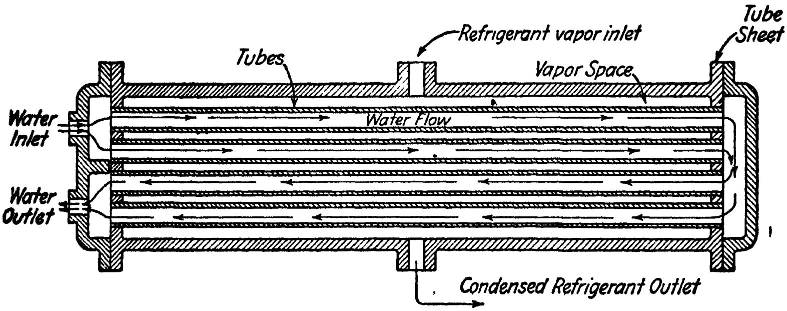


FIG. 4-3. Section of horizontal shell and tube condenser.

Heat Transfer in Horizontal Multipass Shell-and-tube Condensers. Kratz, Macintire and Gould have presented data on shell-and-tube ammonia condensers and have made a table of conclusions regarding their design and operation. These values in graph form appear in Figure 4-4.

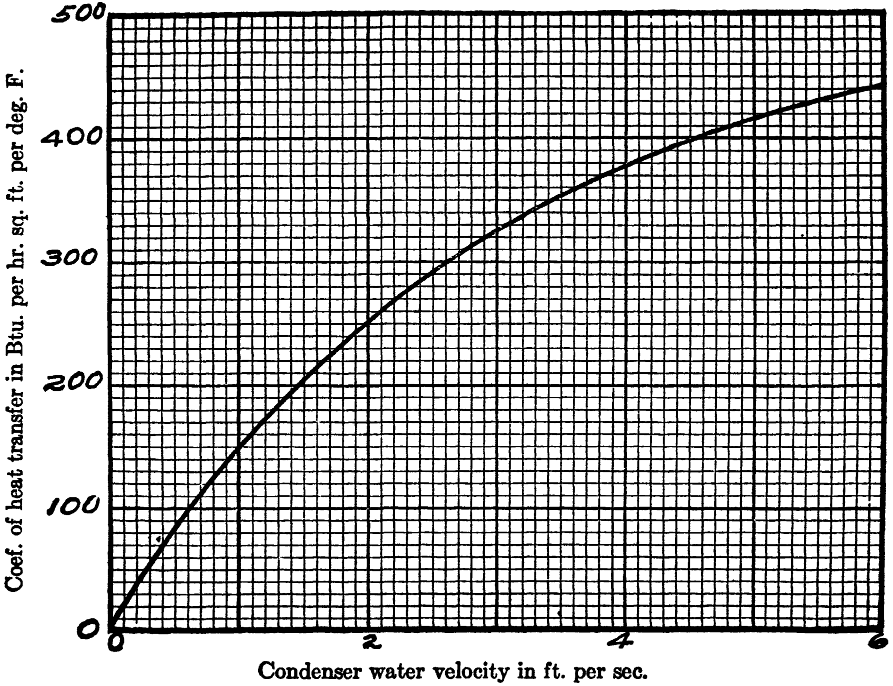


Fig. 4-4. Relation of heat transfer rates to water velocities in a horizontal shell-and-tube condenser. (*Values mostly from work of Kratz, Macintire and Gould, Bull. 209, Eng. Ex. Station Univ. of Illinois.*)

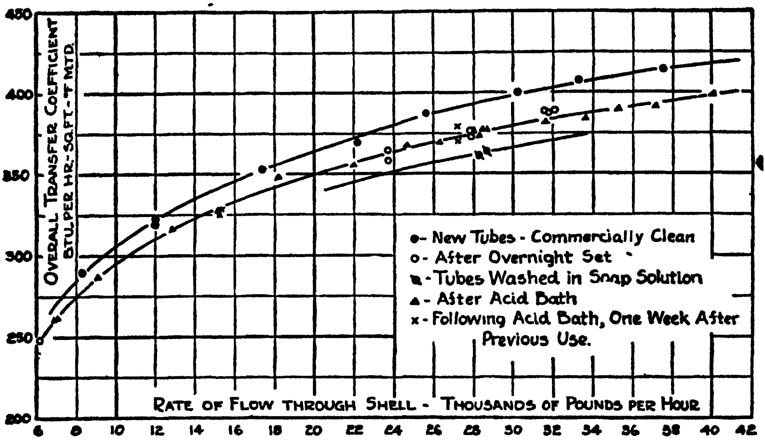


FIG. 4–5. Curves showing effect of different degrees of cleanliness of tube surfaces and results of two methods of cleaning.
(*From* Byron E. Short, Bull. 4324, Bureau of Engineering Research, Univ. of Texas)

CONCLUSIONS

The following conclusions may be drawn from this investigation, subject to such limitations as may be imposed by the range covered and by the conditions specifically stated, under which the tests were run:

(1) For a given initial water temperature and given weight of cooling water per minute the increase in total tonnage is directly proportional to the increase in condenser pressure expressed in pounds per square inch gage.

(2) The actual total capacity developed is governed by the amount of condensing surface, the limiting condenser pressure, the temperature of the water available, and the amount of water circulated.

(3) For a given difference between the ammonia saturation temperature and the initial water temperature, the condenser pressure has no material effect on the total tonnage developed with a given weight of water circulated per minute.

(4) For a given difference between the ammonia saturation temperature and the initial water temperature, the increase in tonnage developed is directly proportional to the increase in weight of cooling water circulated per minute.

(5) For given water velocities through the condenser tubes, lower values are obtained for the coefficients of heat transfer when the two identical shells of the condenser are connected in series than when they are connected in parallel.

(6) The most effective arrangement for condensing surface is one in which the water travel is comparatively short, and which offers a large area for the action of the coldest water near the point of entry.

(7) For a given weight of water circulated per minute per square foot, a higher value for the coefficient of heat transfer and for the total tonnage developed is obtained when the two identical shells of the condenser are connected in series than when they are connected in parallel, but these higher values are accompanied by greatly increased friction pressure losses, and hence increased power is required to circulate the cooling water.

(8) The decrease in the heat transmission caused by fouling of the tubes is very marked during the first four hours of running subsequent to cleaning. At the end of this time the effect of scale formation materially decreases and the rate of heat transfer becomes practically constant over a wide range of water rates.

(9) For a given tonnage developed and a given water rate, fouling of the tubes results in greatly increased temperature differences between the saturated ammonia and the cooling water and in greatly reduced coefficients of heat transfer.

(10) For a given initial water temperature the condenser tonnages developed per square foot of condensing surface over a range of volumes of water circulated per minute per square foot can be represented by a mean curve, with deviations not exceeding 8% for any of the condensers tested. It is possible that these curves may be of more practical value than those for mean coefficients of heat transfer.

(11) The general equations, now existing in the literature, for heat flow in condensers may be used within limits of 10% to predict the coefficients of heat transfer obtained for the multitube-multipass ammonia condenser under the conditions and over the range of water velocities used in these tests.

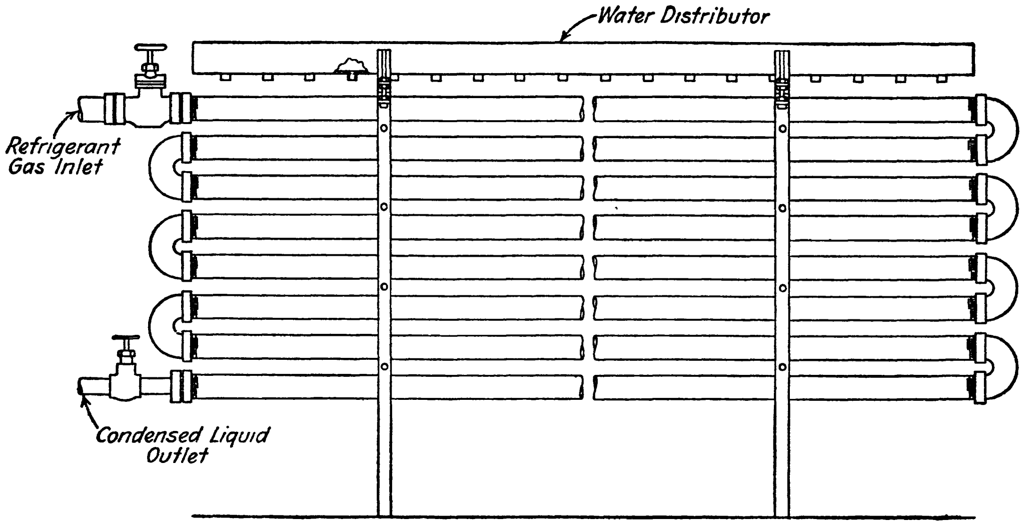
(12) More fundamental work should be done with tube arrangements corresponding to those found in commercial types of condensers in order to establish factors in the equations to render them more generally and more strictly applicable to the various types.

EVAPORATIVE CONDENSERS

In areas where water is scarce, it is necessary to economize in its use. This is usually accomplished by evaporative cooling. The water may be sprayed into the air over a pond or may be passed through a cooling tower which provides a large wetted area for evaporation. The cooled water is then pumped to a condenser and serves to liquefy the refrigerant. The evaporative condenser is, in effect, a combined cooling tower and condenser in which heat is transferred from a condensing refrigerant to a layer of water; it then passes by evaporation to the air as latent heat of water vapor. Since the latent heat of water at atmospheric temperature is approximately 1050 Btu per lb. and the sensible cooling effect does not usually exceed 25 Btu per lb., the great saving in water will be appreciated.

Atmospheric Condensers. The atmospheric condenser (Figure 4–6 is a simple and rugged piece of equipment in which compressed refrigerant vapor is passed through a pipe coil over which water is continuously sprayed or cascaded. It is usually formed of a series of parallel horizontal pipes connected by return bends to form a continuous coil which is mounted in a vertical plane and supported by upright members. Screwed or welded return bends may be used, or a continuous tube may be bent to the required "hairpin" coil form. Water from a perforated pipe or trough flows over the topmost pipe, cascades over each lower pipe and drops into a catch basin or pan. Refrigerant vapor enters at the top and condensed liquid is discharged from the bottom of the coil. When no evaporation occurs from the wet surfaces, this type condenser operates on the parallel-current principle, since the entering warm refrigerant vapor meets the coolest condensing water. The major part of the heat is transferred through the walls of the topmost coils and very little transfer occurs through the lower coils, which are in contact with relatively warm water. For this reason the condenser stands are usually limited to ten or twelve horizontal pipes when cool water is supplied from an external source. Splash strips of sheet metal or thin wood are frequently inserted between the pipes in order to prevent splashing and loss of water.

When the atmospheric condenser is located where a free circulation of air is permitted and reasonably constant winds prevail, it becomes an evaporative condenser and may be cooled entirely by



ATMOSPHERIC CONDENSERS—PARALLEL FLOW

FIG. 4-6.

vaporization from the wet pipe surfaces and from the surface of the cascading water. The flowing water is maintained at an approximately constant temperature, since heat is removed by evaporation as rapidly as it is gained from the condensing refrigerant; hence, the number of effective pipes in a stand of the evaporative condenser is not limited by the initial temperature of the water.

Advantages of the Atmospheric Condenser.

(1) In regions where the available cooling water contains large quantities of scale-forming minerals in solution, the atmospheric type is the most easily maintained condenser. Water cascades over the outside of the pipes and scale cannot retard the full rate of flow. The quantity of scale on the cooling surface is at once evident and, if necessary, the tubes may be cleaned while the condenser is operating.

(2) The entire cooling surface is in sight and readily accessible; thus, leaks may be readily located and repaired. A characteristic deposit is formed upon the surface when leaks occur in an ammonia condenser and the bubbling of escaping refrigerant also serves to reveal leakage.

(3) The power required to pump cooling water is merely that of raising the required quantity from the supply source to the top of the condenser stand.

(4) The total condensing surface is usually divided into several separate stands which are provided with valved connections to the compressor discharge line and the liquid refrigerant line. Thus, in case of leakage one section may be cut off for repairs while the other stands will permit the system to continue in operation.

(5) When ample air circulation is possible the water consumption is very low, since the unit serves as a combined cooling tower and condenser.

(6) Cleaning is simple and easily accomplished without removing any parts to gain access to the water surfaces, and a simple scraping or wire brushing is usually sufficient.

(7) This type condenser is undamaged by freezing, and in cold weather the water supply may be reduced or entirely cut off and operated by air-cooling alone.

The atmospheric condenser cannot be used where splashing water or spray is prohibited, and in general it is limited to outdoor locations. In cities or near public thoroughfares careful shielding is necessary to prevent the nuisance created by sudden gusts of wind which may carry the spray over a considerable distance. Where space is at a premium, the floor area requirements of the atmospheric condenser are a disadvantage. The highest heat transfer efficiency cannot be attained when parallel flow of cooling water and refrigerant is employed; however, this disadvantage is obviated when the unit is used as an evaporative condenser.

Bleeder Condensers. The atmospheric type condenser may be operated on the counter-current principle by admitting vapor at the bottom of the coil and providing liquid drains or "bleeder" connections from each horizontal pipe to the liquid refrigerant receiver (Figure 4–7). Thus, the vapor may pass upward from pipe to pipe in a direction opposite to the water flow, while liquid refrigerant leaves the coil as soon as it is condensed. No appreciable subcooling of the liquid occurs in the bleeder condenser, although it is possible to pass the liquefied refrigerant through a separate coil in case further cooling is necessary.

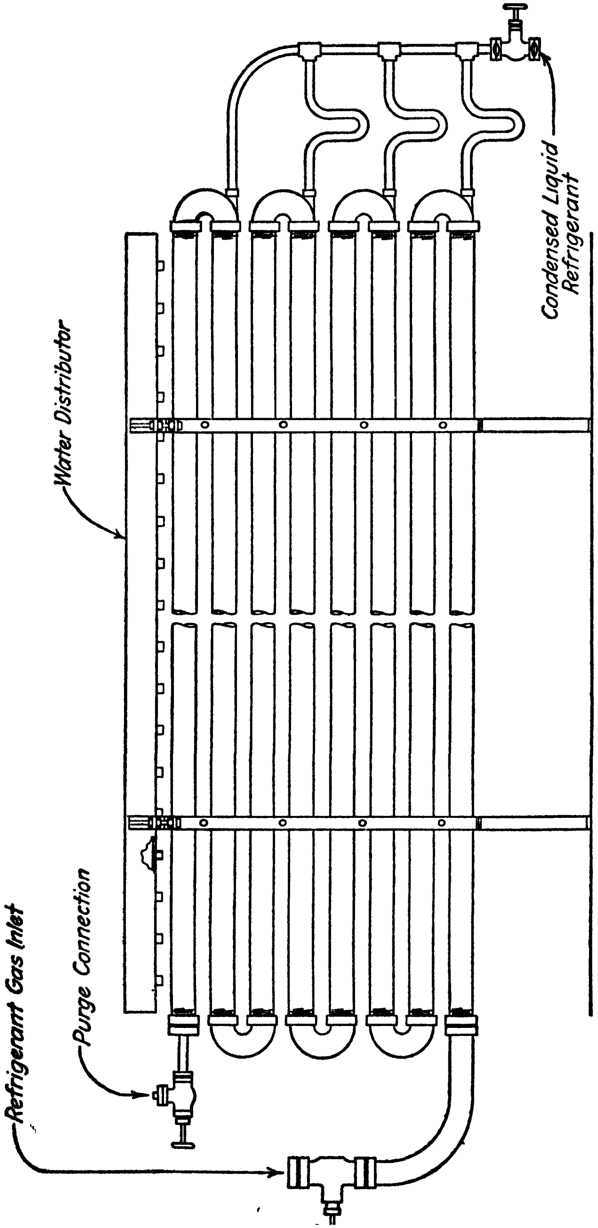
Heat Transfer in Atmospheric Bleeder Condensers. Over-all heat transfer coefficients have been determined by Kratz, Macintire and Gould for an atmospheric bleeder type ammonia condenser consisting of twelve 2-in. pipes, each 20 ft. in length and equipped with a bleed connection for each pair of horizontal pipes. Their data may be expressed by the equation:

$$U = 178 + 11.3w,$$

in which U is the over-all heat transfer coefficient for condensing ammonia and w the pounds water per minute per foot of condenser stack.

The loss of water from the atmospheric condenser is given by Figure 4–8, which is taken from the same report. This condenser was tested indoors and it is evident that the loss was not augmented by wind. Apparently the loss is designated as the quantity which did not smoothly flow from pipe to pipe, the bulk of which may be recovered by a sufficiently wide catch basin.

Forced Air Circulation Evaporative Condensers. Where space is limited and the prevailing winds are unpredictable, the evaporative condenser which depends upon power-driven fans for air circulation is widely used to conserve water. This is, in effect, a combined forced-draft cooling tower and condenser, through which only a small quantity of water is circulated while heat is continuously supplied by condensing refrigerant as water is evaporated. The unit is more compact than a separate cooling tower,



BLEEDER TYPE ATMOSPHERIC CONDENSER

FIG. 4-7.

pump and condenser, and in addition the cost of pumping water is decreased.

The design comprises a series of condenser tubes or coils, which may be either the plain- or extended-surface type. A water spray maintains the surfaces in a moist condition and a power-driven fan directs a current of air over the wet surfaces to promote rapid evaporation. Compressed refrigerant vapor enters the tubes and is discharged in the liquid state to the receiver, while a series of baffles removes entrained water droplets from the leaving air stream. Figure 4-9 illustrates the operating principle of a unit employing recirculation of the cooling water.

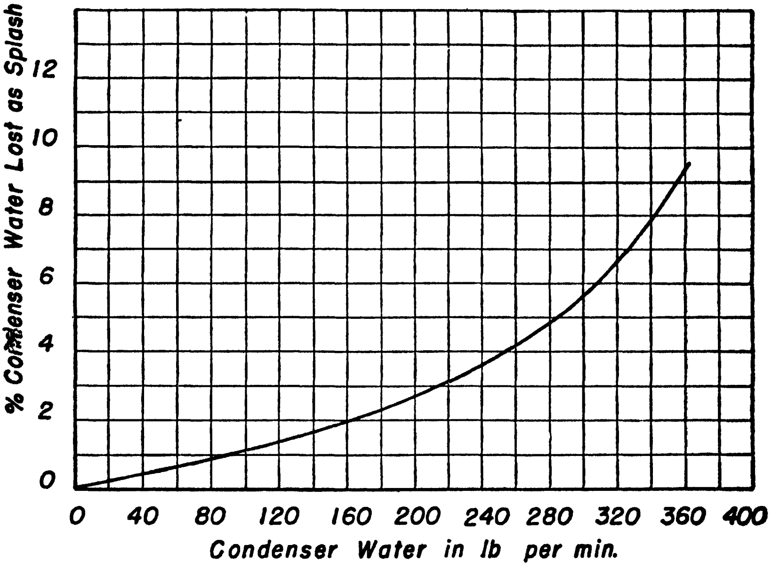


FIG. 4-8. Splash loss at different rates of atmospheric bleeder condensers as determined by Kratz, Macintire and Gould.

Forced-draft evaporative condensers are built in units from approximately 0.5 ton to 100 tons rated capacity. Small sizes may have the spray nozzles connected directly to the water supply system and run the unevaporated portion to waste, but larger units employ a power-driven pump to recirculate water over the heat exchange surfaces. In cases where appreciable amounts of scale-forming material are dissolved in the water, rapid fouling of

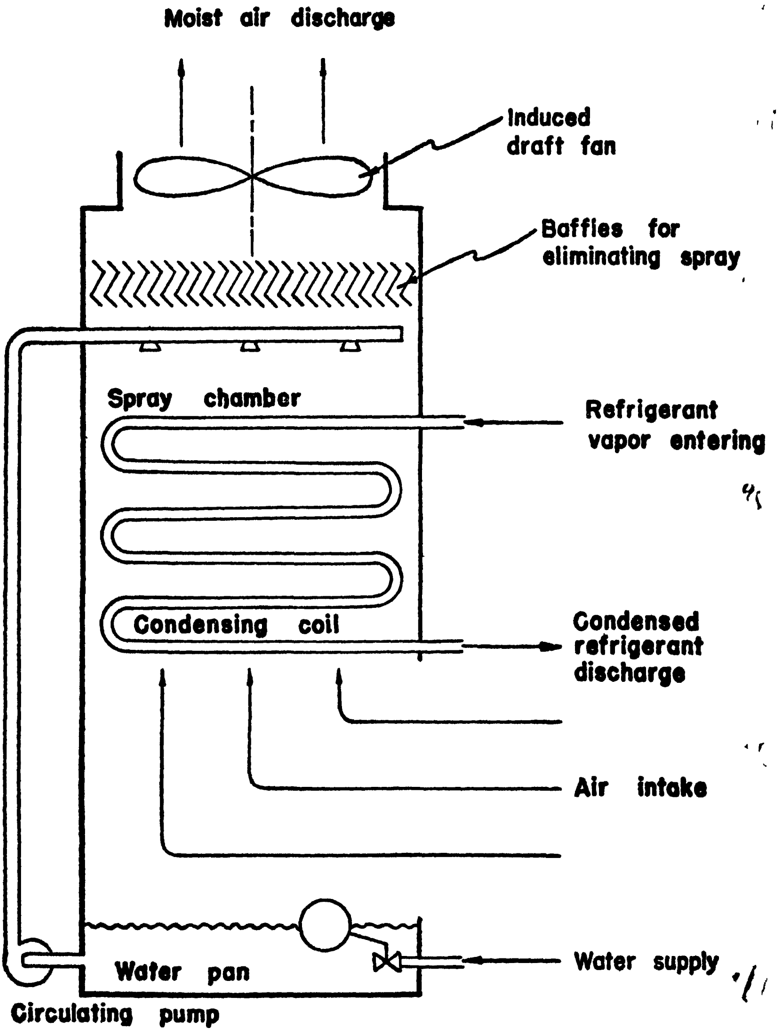


FIG. 4–9. Functional diagram of forced air circulation evaporative condenser.

the surfaces will occur from concentration of the impurities by evaporation. Therefore, it is necessary to add chemicals to prevent the formation of hard scale and to periodically run the water to waste in order to avoid building up a high concentration of impurities. Corrosion of metal parts is accelerated by the combination of water spray, atmospheric oxygen and dissolved salts, which occurs in the evaporative condenser, but anti-corrosive agents may be used successfully in the recirculating water system.

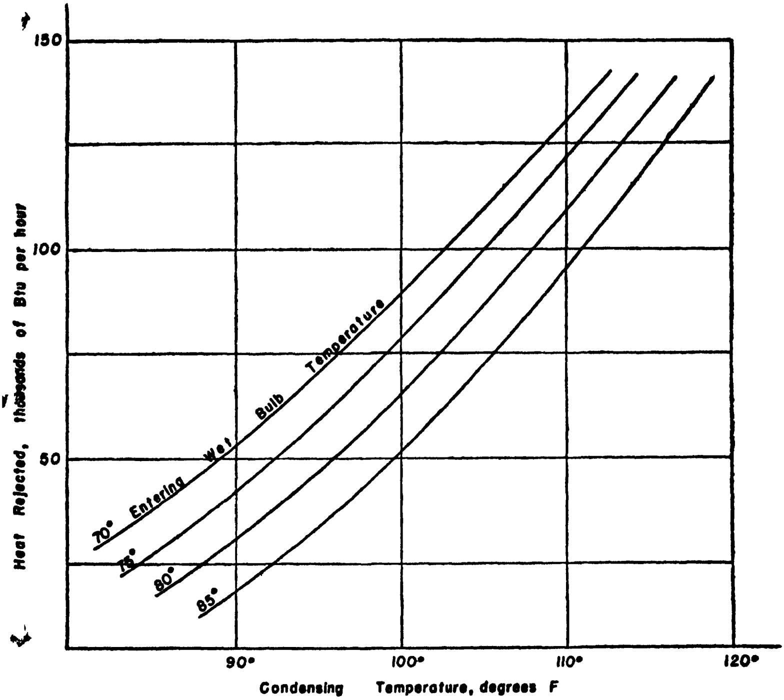


FIG. 4–10. Graph showing capacity of evaporative condenser having 96 sq. ft. heat transfer area and supplied with 1500 cu. ft. per min. of air. (*From Carrier Corporation, by permission.*)

The water evaporation rate increases rapidly when the surface temperature increases with a rise in condensing pressure and when the wet bulb temperature of the entering air decreases. The effect of these variables is shown graphically by Figure 4–10.

AIR-COOLED CONDENSERS

In general, the refrigerating machine condenser is directly cooled by air only in small systems. The low rate of heat transfer to circulating air requires a large condensing surface and raises the initial cost of the condenser. However, the simplicity of this type and the elimination of water connections has resulted in the almost universal adoption of air-cooled condensers for domestic refrigerators and commercial units of less than 0.5 ton capacity. Standard air-cooled condensing units are made in sizes up to approximately 3 tons and are frequently employed in areas where the available water is expensive or highly charged with scale-forming minerals. For railway and motor vehicle air conditioning, the refrigerating system is equipped with air-cooled condensers to reduce weight.

Finned or other types of extended-surface tubes are used in the construction of many air-cooled condensers. The fins may be formed by winding a strip of sheet metal edgewise around the tube to form a helicoidal surface and dipping the assembly into molten solder or zinc to secure good thermal contact between tube and fins. A second method consists in forcing punched sheets over the tube and bonding with molten metal or expanding the tube to secure good mechanical contact. Longitudinal fins which are an integral part of the tube may be formed by the extrusion process or they may be formed of sheet metal and welded to the tube wall. Another interesting extended surface is formed by gouging a thick-walled tube with a special tool so that the chips curl up to form a series of spines upon the tube surface. Condensers are formed by bending the tubing into coils of the desired shape or by connecting straight sections with return bends or headers. Such units are usually provided with power-driven fans to secure positive air circulation, but in small units a suitable duct arrangement may be used to produce circulation by means of the chimney effect.

The familiar automotive radiator type of heat transfer surface has been adapted to refrigeration service by making it sufficiently strong to resist the applied pressure. A very compact and lightweight condenser is obtained, which is well adopted to mounting in a casing with its circulating fan and drive as a single unit.

Plate type condensers are constructed by forming and welding together two sheets of metal in such a manner that a hollow flat plate is obtained. Bulging of the flat surfaces under pressure is prevented by dimpling one sheet and spot-welding it to the other so that the effect is similar to the familiar stay bolts used in steam boilers. The completed assembly is mounted in a vertical plane; warm, compressed refrigerant vapor enters at the top and is cooled by thermal currents of air. This type of condenser is used only for domestic refrigerators.

NONCONDENSABLE GASES IN THE SYSTEM

During the operation of a refrigerating system, air may leak into portions of the apparatus which are at subatmospheric pressure or noncondensable gases may be formed by decomposition of the refrigerant or the lubricating oil at the high temperatures attained in the compressor. These gases are carried to the condenser and to the liquid receiver, where their presence results in an unnecessarily high condensing pressure and reduced condenser capacity.

Efficient operation requires that the quantity of these gases be kept at a minimum by consistent purging of the condenser and liquid refrigerant receiver. An increase of approximately 4% in the power requirements of an ammonia system is caused by sufficient noncondensable gas to raise the condenser pressure by 10 lbs. per sq. in. while the power waste for a Freon-12 system under similar conditions will be approximately 7%. While it might seem that a considerable amount of noncondensable gas might be required to raise the condenser pressure by 10 lbs. per sq. in., the presence of only 0.5 lbs. of air, equivalent to 6 cu. ft. at atmospheric pressure, will cause this increase in the average condenser of 10 tons capacity.

Careless purging can waste appreciable quantities of refrigerant, but lack of purging can waste energy costing many times the price of the lost refrigerant. One frequently hears the statement that a system should be purged after it has been shut down for a time to allow the lighter noncondensable gases to separate from the refrigerant vapor. While the advice is excellent, the reasoning is fallacious. It is pointed out that all gases and vapors are completely miscible in a manner which is similar to the mutual solubility of water and alcohol, but separation will not occur as a result of standing in either case. However, at sufficiently low temperature nearly all the refrigerant vapor may be condensed and the noncondensable gas is thus left essentially free of refrigerant. In general, the condenser is coolest when the compressor is idle and

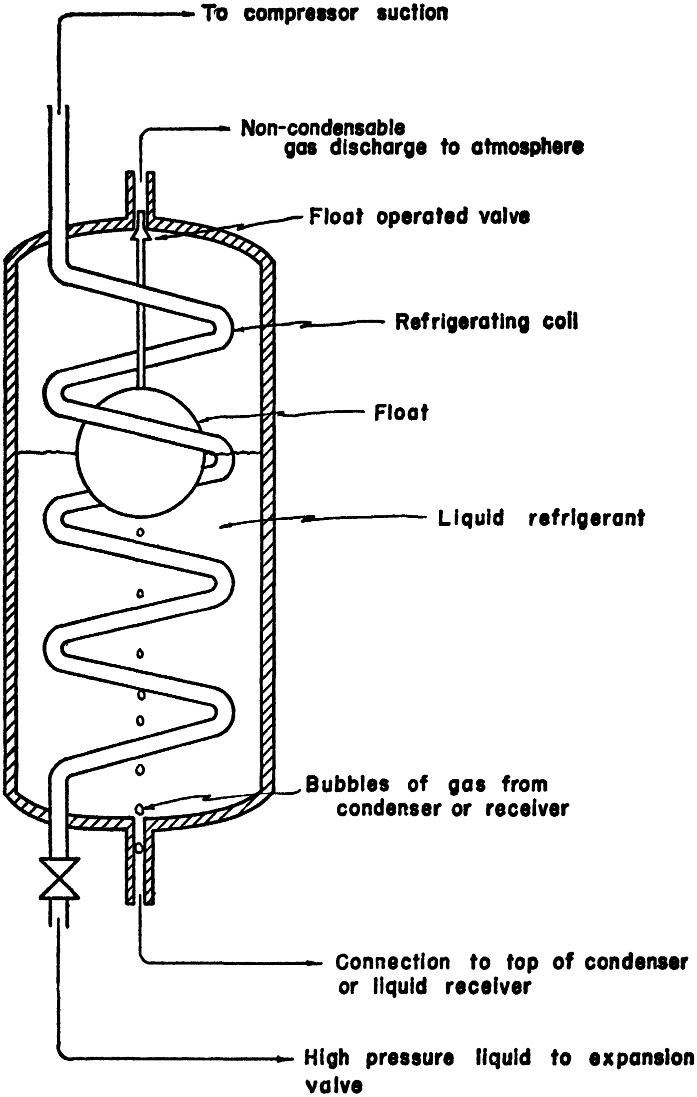

To compressor suction
Non-condensable gas discharge to atmosphere
Float operated valve
Refrigerating coil
Float
Liquid refrigerant
Bubbles of gas from condenser or receiver
Connection to top of condenser or liquid receiver
High pressure liquid to expansion valve

FIG. 4–11. Section through an automatic non-condensable gas purger.

thus there is less refrigerant vapor mixed with the gas than when the condenser is operating at full capacity.

Special devices for purging consist of a refrigerated chamber connected to the gas space of the condenser or liquid receiver in such a manner that gas and vapor enter at the bottom. Refrigerant vapor is condensed as soon as it enters and fills the chamber completely with liquid, except some space at the top, which is occupied by cold noncondensable gas. As more gas enters, liquid is displaced and returns to the receiver. When a certain quantity of gas has been trapped, it is blown to waste through a valve at the top of the chamber. This valve may be manually operated or it may be controlled automatically by means of a float. Figure 4–11 shows the method by which this type of purger discharges noncondensable gas from the system.

SECTION V

REFRIGERATING CYCLES

Refrigeration is defined as the art of producing and maintaining, in a given space, a temperature level which is lower than that of the surroundings. Low temperature is produced in the space by removing the heat which is initially present in the enclosed air and in any materials which may be present. To maintain low temperature it is necessary to remove heat as fast as it enters the space. Heat may enter the refrigerator by conduction through the insulated walls, by leakage of air through open doors or by bringing in warm materials to be cooled. It may originate in the cooled space as the heat of chemical reactions occurring in the stored material, as energy given off by living tissues such as fruits and vegetables, or as the body heat of workmen. Electric lights, fans, and other mechanisms operating in the refrigerator also contribute heat which must be continually removed to sustain the low temperature. It is well known that normal heat transfer occurs only from a body at one temperature to bodies which are at lower temperatures, and that this transfer is somewhat analagous to the flow of water from an elevated reservoir to a lower level. However, by performing work, water may be carried or forced to flow from a low level to an elevated reservoir and, in a somewhat similar manner, heat may be removed from a low-temperature region and transferred to a region of higher temperature.

This might be accomplished by continuously carrying very cold objects into the refrigerator, allowing them to absorb heat and then removing them, together with the absorbed heat. Such a procedure is similar to swabbing water from an excavation by means of dry sponges and is completely satisfactory until the supply of very cold objects is exhausted or all of the dry sponges are saturated with water. What is needed is some method of squeezing the water from the sponges or of removing the absorbed heat from the objects. Such a method will permit a small number of sponges to keep the excavation unwatered or will allow the removal of the desired quantity of heat from the refrigerator without having an unlimited supply of the cold objects.

A change of state, such as the change of ice to liquid water, absorbs large quantities of heat at low temperature and this method is widely used to secure refrigeration. Unfortunately, no simple and direct process is known by which the absorbed heat can be removed and the water returned to ice; it is therefore necessary to have a continuous supply of ice which has been formed in cold weather and stored, or which has been produced by some other method of refrigeration.

When work is done upon an elastic body, heat is liberated; that is, the temperature of the body is raised and, conversely, when an elastic body is allowed to perform work, heat is absorbed and the temperature drops. This may be shown very simply by means of a rubber band. The band is held between the thumb and forefinger of each hand and is then quickly stretched to several times its original length. Upon touching the stretched band, it will be found to be quite warm, and the process of stretching very definitely requires work. If the band is held in the stretched condition for a few seconds, it will lose this heat to the air and will once more be at the temperature of the surroundings. Now allow the stretched band to do work quickly by drawing the hands together, thereby returning the rubber band to its original length. It will feel distinctly cold to the touch.

Although the rubber is not a very satisfactory medium for large-scale work, the principle has been applied to air and many installations of air refrigerating machines have been made. Work is done upon air by compressing it to a high pressure, during which process it becomes very hot. The heat is removed by passing the compressed air through a coil which is cooled by exposure to the surrounding air or by water. When the cooled, compressed air is allowed to do work by expanding in an engine or against a turbine wheel, it becomes exceedingly cold and may be used to absorb heat from the refrigerator. This system operates satisfactorily, but the apparatus is bulky and expensive, large losses of energy are unavoidable and it has been very largely abandoned in favor of the more efficient vapor compression system.

Vapor-compression Refrigerating Machines. The vapor-compression refrigerating system operates in a cycle which is similar to that of the air system, except that instead of using a noncondensable gas a vapor is selected which, when compressed, may be condensed to a liquid at ordinary atmospheric temperatures. After condensation, pressure is suddenly released and the liquid is allowed to do work by expanding to the vapor state. This work consists of separating the molecules of the substance sufficiently far so that the vapor state is attained. Since energy must be supplied to do this work, it is taken from the liquid itself, thus producing low temperatures and, as evaporation proceeds, the remaining necessary energy is absorbed from the refrigerator. The cooling effect of an evaporating liquid is quite familiar. When the hands are wet with water or any liquid which evaporates rapidly, a distinct sensation of coolness is experienced, which persists until the liquid is completely evaporated. Heat is removed from the skin to supply the energy required to vaporize the liquid; this process is identical in principle with the process which occurs in the refrigerator evaporator. To complete the refrigerating cycle, the vapor is removed from the low-pressure evaporator and is compressed by a suitable pump to the high pressure required for condensation.

The essential parts of the vapor compression system are:

(1) A device which compresses the vapor to the condenser pressure. During this process the temperature of the vapor increases sufficiently so that heat may be discharged to the surroundings.

(2) A condenser in which the compressed vapor is cooled by a stream of water or by atmospheric air, and in which the heat, which has been added in the refrigerator and by the compresser, is removed.

(3) The expansion valve which regulates the flow of liquid refrigerant from the high-pressure portion of the system to the evaporator and reduces the pressure sufficiently so that evaporation can occur at the low temperature of the refrigerator.

(4) The evaporator in which the liquid refrigerant is permitted to do internal work at a low pressure and thus removes heat from the refrigerator.

In addition to these four essential parts, it is of course necessary to provide a source of energy for the operation of the compressor, piping to connect the units of the system and the necessary valves and accessories to permit proper control and operation of the system.

Thus, in effect, a complete heat conveyor is formed by which the refrigerant in the liquid state enters the refrigerator, picks up a large quantity of heat at low temperature and carries it out of the refrigerator. Here the conveyor is raised to a high temperature by the compressor and then passes to the condenser, where the load of heat is discharged to the surrounding atmosphere or to a stream of water. When the heat has been discharged the vapor is converted to the liquid state and is then returned to the refrigerator to pick up another load of heat.

Reversed Heat Engines. When a heat engine is reversed it becomes a heat pump or refrigerating machine. The heat engine takes in a quantity of heat at high temperature, converts a portion to mechanical energy and discharges the remaining portion at a moderate temperature. When the engine is reversed, it takes in a portion of heat at moderate temperature, adds a portion of mechanical energy and discharges the total quantity of energy as heat at high temperature.

The vapor-compression refrigerating machine is identical in principle with the reversed steam-power-plant cycle. In the steam plant, heat from burning fuel enters the boiler and converts water into vapor at high temperature and high pressure. The steam flows to an engine or turbine, where the temperature and pressure are reduced and a portion of the heat energy is converted to mechanical energy. Exhaust steam leaves the engine at moderate temperature and low pressure, enters the condenser, discharges its remaining heat energy to a stream of cool water, and reverts to the liquid state. It is advantageous to maintain the condenser at a low temperature in order to recover the greatest possible portion of the heat in the steam as mechanical energy; however, this is usually fixed by the temperature of the cooling-water source. The cycle is completed when the condensed steam is forced back to the boiler by means of a feed pump which may be driven from the main engine or by an auxiliary motor.

A vapor-compression refrigerating machine also uses an evaporator or boiler, but for such an application it is filled with some liquid which evaporates readily at low temperature. When placed inside the refrigerator, heat is absorbed and the liquid contents are converted to vapor at low pressure and low temperature. A compressor receives this vapor with its content of low-temperature heat energy, raises its pressure by means of energy supplied from some suitable outside source and then discharges the total energy as the moderate-temperature heat of the compressed vapor. The warm compressed vapor now passes to the condenser, discharges its heat energy to some suitable cooling agent, such as a stream of water, and returns to the liquid state. Since the liquefied refrigerant in the condenser is at a higher pressure than that prevailing in the evaporator, no boiler feed pump is required to complete the cycle. Instead, liquid is introduced into the boiler or evaporator through the expansion valve, a process which is completely irreversible and which wastes all the available energy of the high-pressure liquid. A suitable engine could return this wasted energy to the compressor and secure additional refrigerating effect, but the added complication has prevented its use. The simplicity of the expansion valve and the close control which it affords have made its adoption universal in spite of the inherent waste of refrigerating effect. The similarity of the two cycles is portrayed by the diagrams of Figure 5-1.

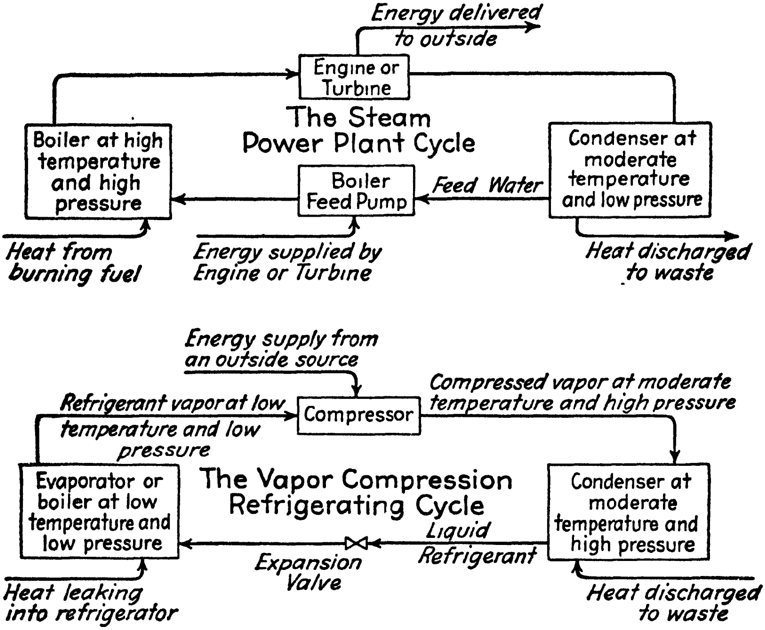

Energy delivered to outside
Engine or Turbine
The Steam Power Plant Cycle
Boiler at high temperature and high pressure
Boiler Feed Pump
Feed Water
Condenser at moderate temperature and low pressure
Heat from burning fuel
Energy supplied by Engine or Turbine
Heat discharged to waste
Energy supply from an outside source
Compressed vapor at moderate temperature and high pressure
Refrigerant vapor at low temperature and low pressure
Compressor
Evaporator or boiler at low temperature and low pressure
The Vapor Compression Refrigerating Cycle
Liquid Refrigerant
Condenser at moderate temperature and high pressure
Expansion Valve
Heat leaking into refrigerator
Heat discharged to waste

FIG. 5-1.

REFRIGERATION THERMODYNAMICS

A reversed Carnot cycle would be the ideal refrigerating machine, since it would transfer heat from the refrigerator to a condenser or waste-heat reservoir at higher temperature with the expenditure of the least amount of work or mechanical energy. Such a cycle cannot be attained in practice, but it does serve as a standard of comparison for actual refrigerating machines and as a goal which the engineer is striving to reach. In the refrigerating machine, the useful effect is the removal of a quantity of heat Q_r from the refrigerator at the temperature T_o. The quantity of work W/J must be expended to convey the heat to a condenser at the higher temperature T and to discharge the quantity of heat Q_c to waste.

From the First Law of Thermodynamics the relation between these energy quantities is expressed by the equation

$$Q_r + \frac{W}{J} = Q_c. \tag{1}$$

This relation imposes no limit to the ratio between the work done and the heat removed from the refrigerator, but the Second Law of Thermodynamics states that the maximum amount of heat transferred cannot exceed the value given by the equation

$$Q_r = \frac{W}{J}\left(\frac{T_o}{T - T_o}\right). \tag{2}$$

A relation known as the coefficient of performance is the ratio between the heat transferred from the refrigerator and the work which is required for its removal. For any cycle this is represented by the expression $\frac{Q_r}{W/J}$ and is frequently designated by the letters *cop* or the Greek letter β. The coefficient of performance of the Carnot cycle may be determined by rearranging equation 2 thus,

$$cop_{\text{Carnot}} = \frac{Q_r}{W/J} = \frac{T_o}{T - T_o}.$$

It is to be emphasized that the coefficient of performance is not the efficiency of the machine, but that it is a ratio which is useful for comparing two machines. It may also be used to compute the work for any system which is to operate under known conditions and to remove a known amount of heat from the refrigerator. Thus, the horsepower of a machine producing N tons of refrigerating effect is given by the equation

$$\text{hp.} = \frac{4.71N}{cop}.$$

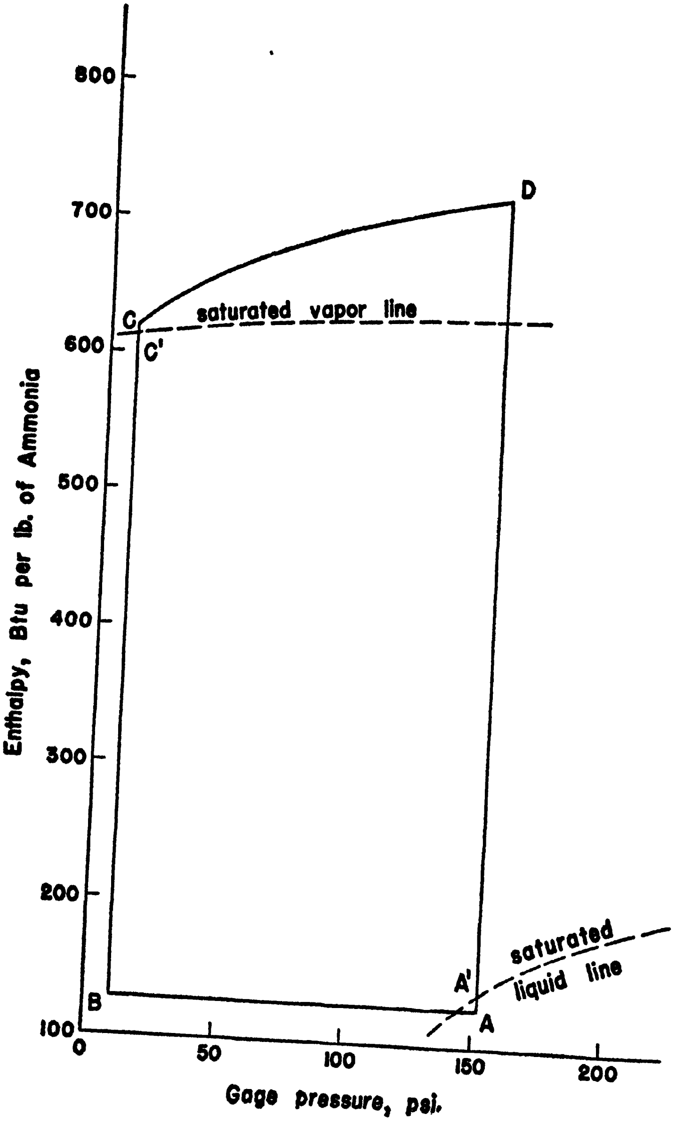

800
700
600
500
400
300
200
100
Enthalpy, Btu per lb. of Ammonia
D
C
C'
saturated vapor line
A'
A
B
saturated liquid line
0
50
100
150
200
Gage pressure, psi.

FIG. 5–2.

The cycle of the actual vapor refrigerating machine deviates from that of the reversed Carnot cycle in several respects:

(1) The working vapor is compressed to condenser pressure and is thus raised to a temperature which is considerably higher than that of the condenser. This necessitates that the superheated vapor be cooled to saturation in the condenser, which is an irreversible process that wastes energy.

(2) Expansion of the liquid from condenser pressure to evaporator pressure is accomplished by throttling, which is also an irreversible process.

The energy relations may be most readily determined by following one pound of the refrigerant in passing through the system and noting the changes which it undergoes as energy is absorbed or given up. As a typical example the standard rating cycle for ammonia will be used and the changes may be followed on the diagrams of Figure 5–2, Figure 5–3 and Figure 5–4.

The standard rating cycle operates under the following conditions:

(1) Liquefied refrigerant enters the expansion valve at 77° F.

(2) Refrigerant vaporizes in the refrigerator at 5° F.

(3) Vapor enters the compressor in the superheated condition at 14° F.

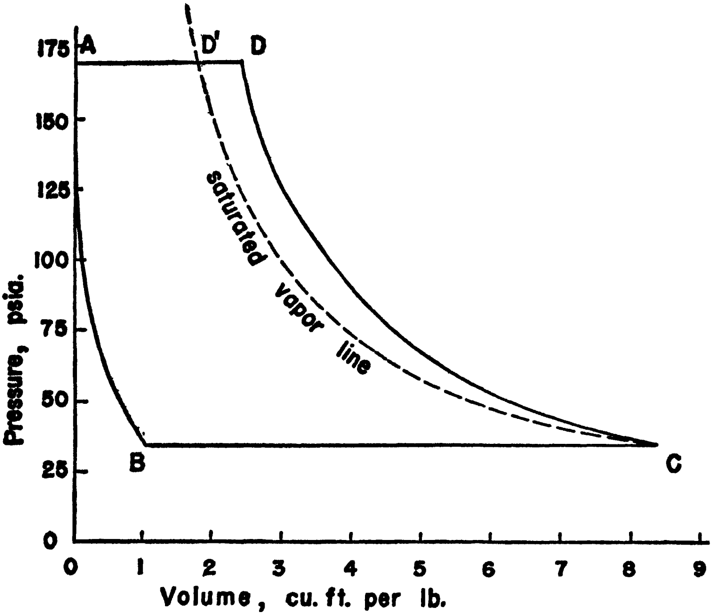
(4) Condensation of the vapor occurs at 86° F and the liquid is then subcooled at constant pressure to 77° F.

Starting at point A on the charts, which represents one pound of the liquid leaving the condenser at 77° F. and 169.2 psia., the following conditions are determined from the ammonia table:

CONDITIONS AT POINT *A* ON THE CHARTS

Temperature	77° F.
Pressure . .	169.2 psia.
Enthalpy or heat content .	128.5 Btu per lb.
Entropy	0.2685 Btu per lb. per °F.
Volume .. .	0.027 cu. ft. per lb.

The liquid enters the expansion valve, its pressure is reduced to 34.27 psia. (saturation pressure at 5° F.), the vaporization of a portion reduces the temperature to 5° F. and the mixture of cold liquid and vapor enters the evaporator. No heat is gained or lost in the expansion valve; hence, the enthalpy remains constant, but the entropy increases. The mixture is now at point *B*.



On the pressure-volume graph, points A and A' are so close as to be indistinguishable.

Fig. 5-3.

Conditions at Point *B* on the Charts

Temperature	5° F.
Pressure	34.27 psia.
Enthalpy	128.5 Btu per lb.
Entropy	0.2818 Btu per lb. per °F.
Volume	1.177 cu. ft. per lb.

In the evaporator, heat is absorbed at constant pressure and temperature, converting the refrigerant to saturated vapor at point *C'*.

Conditions at Point *C'* on the Charts

Temperature	5° F.
Pressure	34.27 psia.
Enthalpy	613.3 Btu per lb.
Entropy	1.3253 Btu per lb. per °F.
Volume	8.150 cu. ft. per lb.

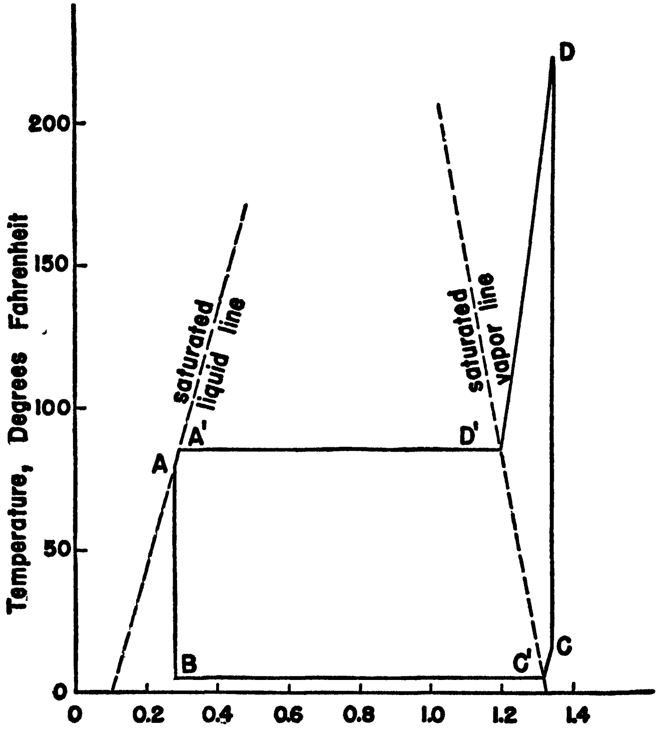


FIG. 5-4.

The change in enthalpy from Point B to C' is caused by the absorption of heat energy from the refrigerator; hence, this heat is the difference between the enthalpy at these points. Thus, the refrigerating effect is

$$\text{Ref. eff.} = h_{C'} - h_B = 613.3 - 128.5 = 484.8 \text{ Btu per lb.}$$

This permits the calculation of the quantity of refrigerant to be circulated per minute to secure one ton of capacity. Since one ton is defined as 200 Btu per min. removed from the refrigerator, the rate of ammonia circulation is computed by dividing the ton equivalent by the refrigerating effect thus:

$$\frac{200}{484.8} = 0.412 \text{ lb. per min.}$$

Upon leaving the evaporator, the vapor will absorb heat from the engine-room atmosphere while passing through the suction line and will arrive at the compressor in the condition represented by point *C*.

CONDITIONS AT POINT *C* ON THE CHARTS

Temperature	14° F.
Pressure	34.27 psia.
Enthalpy	618.3 Btu per lb.
Entropy	1.3365 Btu per lb. per °F
Volume	8.308 cu. ft. per lb.

If it is assumed that the compressor is a perfect machine and that no heat is gained or lost by the vapor during compression, the entropy remains constant and energy is received only in the form of work done by the compressor. The path from *C* to *D* represents the changes during compression. Work is done on the vapor and this results in increasing its temperature and pressure while the volume is decreased.

CONDITIONS AT POINT *D* ON THE CHARTS

Temperature	222.3° F.
Pressure	169.2 psia.
Enthalpy	720.5 Btu per lb.
Entropy	1.3365 Btu per lb. per °F.
Volume	2.413 cu. ft. per lb.

It is now possible to compute the work required by the compressor for one pound of ammonia. Since energy is added only as work, the work expressed as heat units is the difference between the enthalpies at points *C* and *D*, thus:

$$\text{Work} = h_D - h_C = 720.5 - 618.3 = 102.2 \text{ Btu per lb. of ammonia.}$$

As it has been calculated that 0.412 lb. per min. of ammonia must be circulated to secure one ton of refrigeration, the work required for one ton is the product of pounds per minute per ton and work per pound:

$$\text{Work per ton} = 0.412 \times 102.2 = 42.11 \text{ Btu per min.}$$

To convert this to horsepower, divide by 42.40, which is the heat equivalent per minute of one horsepower, thus:

$$\text{Horsepower per ton} = \frac{42.11}{42.40} = 0.993.$$

The coefficient of performance is the heat removed from the refrigerator divided by the required work in heat units. For this cycle it is

$$cop. = \frac{\text{Ref. eff.}}{\text{Work}} = \frac{484.8}{102.2} = 4.747,$$

which indicates that each Btu supplied to the compressor in the form of work will remove 4.747 Btu from the refrigerator. For a Carnot cycle operating between the same refrigerator and the same condenser, the coefficient of performance is

$$cop._{\text{Carnot}} = \frac{T_o}{T - T_o} = \frac{464.6}{545.6 - 464.6} = 5.736.$$

Thus, the efficiency of the ammonia cycle operating between these temperature limits is the ratio between the two coefficients of performance.

$$e = \frac{4.747}{5.736} = 0.829.$$

At point D, the hot compressed vapor leaves the compressor and enters the condenser, where it loses heat to the condensing water. From D to D', superheat is removed and at D' the vapor is saturated at 169.2 psia.

CONDITIONS AT POINT D' ON THE CHARTS

Temperature	86.0° F.
Pressure	169.2 psia.
Enthalpy	611.5 Btu per lb.
Entropy	1.1904 Btu per lb. per °F.
Volume	1.772 cu. ft. per lb.

From D' to A' the latent heat of the vapor is removed at constant pressure and temperature while condensation occurs.

CONDITIONS AT POINT A' ON THE CHARTS

Temperature	86.0° F.
Pressure	169.2 psia.
Enthalpy	138.9 Btu per lb.
Entropy	0.2875 Btu per lb. per °F.
Volume	0.027 cu. ft. per lb.

The liquid is now cooled from 86° F. to 77° F. along the path A' to A and the cycle is complete. Heat discharged to the condenser is the sum of the enthalpy changes from point D to point A and is therefore the difference between the enthalpy of the superheated vapor entering the condenser at D and the enthalpy of the subcooled liquid leaving at A.

Heat discharged $= h_D - h_A = 720.5 - 128.5 =$ 592.0 Btu per lb. of ammonia.

A résumé of the important energy quantities which have been determined for one pound of ammonia passing through this cycle is:

Refrigerating effect	= 484.8 Btu per lb.
Work of the compressor	= 102.2 Btu per lb.
Heat rejected to condenser	= 592.0 Btu per lb.

Since one ton of refrigerating capacity requires the circulation of 0.412 lbs. of ammonia per min., the energy quantities per minute per ton are computed by multiplying the tabulate values by 0.412 thus:

Refrigerating effect per ton	= 200.0 Btu per min.
Work of the compressor per ton	= 42.1 Btu per min.
Heat rejected to condenser per ton	= 244.3 Btu per min.

The actual volumetric displacement of the compressor may be determined in the following manner: At point C the volume of one pound of vapor entering the compressor at 14° F. and 34.27 psia. is 8.308 cu. ft.; thus, the machine must handle this volume for every pound of ammonia circulated through the system. Since one ton of refrigerating capacity requires 0.412 lb. per min. of ammonia, the displacement per minute for one ton is $8.308 \times 0.412 = 4.36$ cu. ft. per min.

In a similar manner it is possible to analyze the cycle of a refrigerating system using any refrigerant for which tables or charts of thermodynamic properties are available. It is necessary to know only the evaporator temperature, the tonnage of refrigeration required and the condenser temperature, in order to determine the rate of refrigerant circulation and the size and power requirements of the compressor.

In general it is safe to assume that the actual displacement of a reciprocating compressor in good condition is 75% of the piston displacement calculated from the bore, stroke and speed of the machine. In part, this is due to incomplete filling of the cylinder because of throttling by the suction valve and also to the reexpansion of compressed gas in the clearance spaces. Throttling by the suction valve depends upon the design and adjustment of the valve itself. Some degree of throttling is unavoidable, but improper valve adjustment can render the machine inoperative. This effect cannot be predicted but must be determined by means of an indicator card. The reduction of capacity due to clearance space may be calculated with precision for any machine operating between known evaporator and condenser pressures. An expression for computing the volumetric efficiency is

$$e_v = 1 - \frac{v_c}{v_p}\left[\left(\frac{P_2}{P_1}\right)^{\frac{1}{n}} - 1\right],$$

in which

e_v is volumetric efficiency,
P_1 is absolute suction pressure,
P_2 is absolute discharge pressure,
v_c is volume of clearance space,
v_p is volume swept out per stroke by the piston,
n is exponent of polytropic compression.

An example illustrates the use of this equation.

Example. A 6-in. x 6-in. twin-cylinder single-acting ammonia compressor operates at 300 rpm. The clearance between the piston and the cylinder head is $\frac{1}{16}$ in. Suction pressure is 15 psia. and discharge pressure is 180 psia. The value of n for water-jacketed ammonia cylinders may be taken as 1.29. Calculate the volumetric efficiency and the actual displacement of the machine.

Solution. The clearance volume in cubic inches is $6^2 \times \pi/4 \times \frac{1}{16}$ and the piston displacement per stroke is $6^2 \times \pi/4 \times 6$. Thus,

$$\frac{v_c}{v_p} = \frac{6^2 \times (\pi/4) \times \frac{1}{16}}{6^2 \times (\pi/4) \times 6} = \frac{1}{96}$$

$$e_v = 1 - \frac{1}{96}\left[\left(\frac{180}{15}\right)^{\frac{1}{1.29}} - 1\right] = 0.939.$$

The actual displacement of the machine is the total piston displacement per minute multiplied by the volumetric efficiency. Thus, there is one compression stroke per revolution for each of the two cylinders and a total of 600 strokes per min. for the machine.

The total piston displacement per minute is $600 \times 6^2 \times \pi/4 \times 6$.

$$600 \times 6^2 \times \frac{\pi}{4} \times 6 = 1{,}018{,}000 \text{ cu. in. per min.}$$

$$600 \times 6^2 \times \frac{\pi}{4} \times 6 = 589 \text{ cu. ft. per min.}$$

Actual displacement = 589 × 0.939 = 553 cu. ft. per min.

THE SUCTION LINE HEAT EXCHANGER

Refrigerating systems are often equipped with heat exchangers in which the cold vapor leaving the evaporator precools the warm high-pressure liquid before it passes through the expansion valve. Some unjustified claims have been made to the effect that the efficiency of systems is increased by their use, but the only case in which an increase can be shown is that in which the evaporator and compressor are connected by a long suction line passing through warm surroundings. In traveling through this line the vapor is superheated and may reach the compressor at a temperature approaching that of the surroundings. Heat acquired by the vapor in this fashion serves no useful purpose and furthermore requires extra compressor work. Now, if this heat can be supplied by the warm high-pressure liquid, the temperature of the vapor will be raised to approximately that of the surroundings and little or no heat will be absorbed during its passage to the compressor. Thus, the work of compression is unchanged, but an increase in refrigerating effect is secured by the cooling of the liquid.

Figure 5–5 represents the cycle of changes for one pound of refrigerant circulating in a system in which the vapor enters the compressor with a considerable degree of superheat. On the temperature-entropy graph (Figure 5–6), vapor leaves the evaporator at conditions represented by point *B*, is superheated to conditions represented by point *C* and enters the compressor without further change. The superheat of the vapor is represented by the area *KBCL*, but its source has no effect upon the work of compression, since, for a given machine, the work depends only upon the initial condition of the suction vapor and the discharge pressure. When the system is operated without a suction-line heat exchanger, the heat removed from the refrigerator is represented by the area *JABK* and the superheat *KBCL* is absorbed from the surroundings without accomplishing any useful effect. With an exchanger, the superheat *KBCL* is absorbed from the liquid, which loses the heat represented by the area *H'G'GH* and the refrigerating effect is represented by the area *J'A'BK*. It may be shown that the areas *H'G'GH*, *J'A'AJ* and *KBCL* are equal; thus, the gain in refrigerating effect *J'A'AJ* is equal to the superheat transferred by the exchanger.

Perhaps these relations are more readily perceived on the

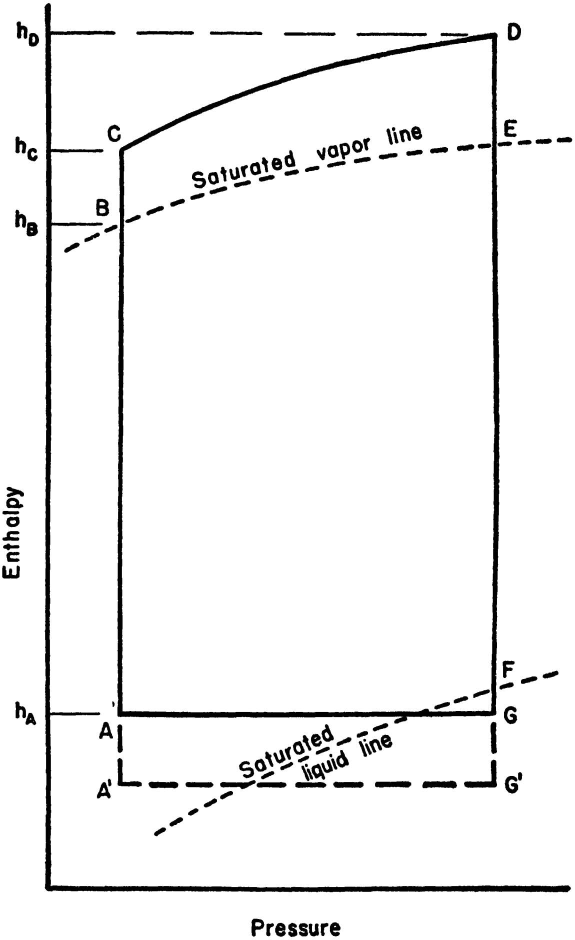


FIG. 5–5. Diagram of refrigerating unit with suction line heat exchanges.

enthalpy-pressure graph (Figure 5–5), since heat is represented by the length of a vertical line. On this chart, the vapor leaves the evaporator at the conditions represented by point *B*. The work of isentropic compression is $h_D - h_C$, the superheat of the low-pressure vapor is $h_C - h_B$, and the heat removed from the refrigerator by a system operating without the suction line heat exchanger is

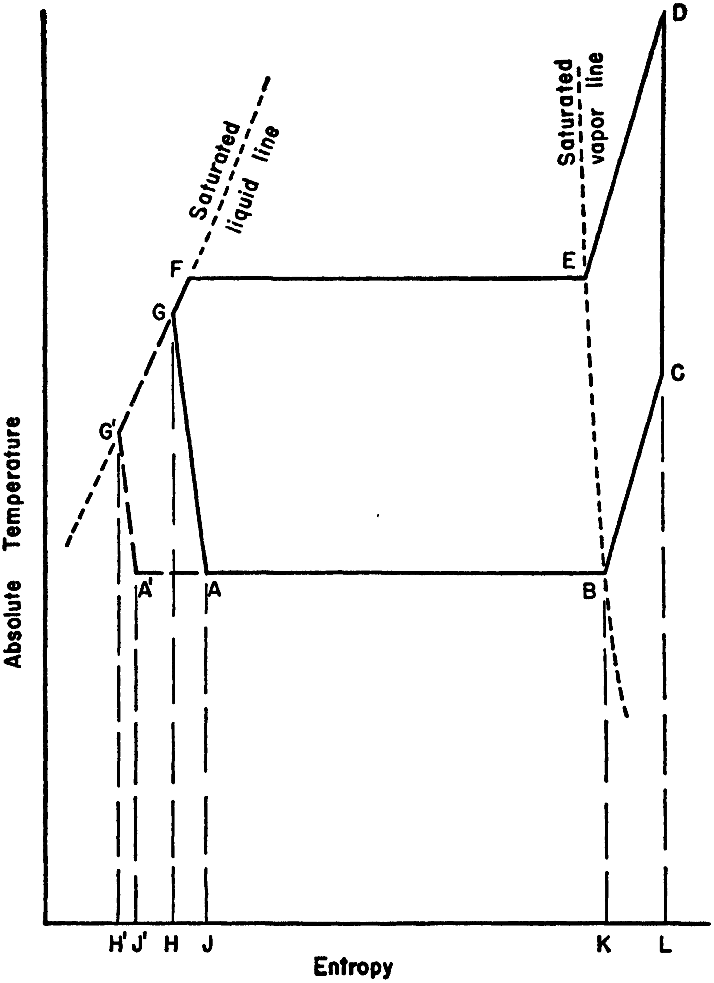


FIG. 5-6. Diagram of refrigerating unit with suction line heat exchanges.

$h_B - h_A$. A heat exchanger transfers the heat represented by *GG'* from the liquid to the vapor and thereby supplies the superheat *BC*, thus increasing the refrigerating effect by the quantity of heat *AA'*.

SECTION VI

ABSORPTION REFRIGERATION

THE ABSORPTION REFRIGERATING MACHINE

The absorption refrigerating system is frequently described in a manner which leads the reader to believe that it is totally unrelated to the vapor compression system which employs a mechanical compressor. Actually it is identical in every respect except one—namely, instead of using a device which is supplied with mechanical energy to compress the vapor, heat or thermal energy is utilized to accomplish this operation. The identity of the two systems is often obscured because a compressor which is operated by thermal energy seems more complex than the familiar mechanical unit. Absorption systems employ condensers, expansion valves and evaporators which are identical with those used in the other system, and the thermal compressor accomplishes exactly the same results as the mechanical compressor.

The function of any compressor is to take in gas or vapor at low pressure, reduce its volume and discharge it at high pressure. The complete cycle of a practical machine which operates continuously is given below:

(1) Vapor or gas at low pressure is taken into the machine.

(2) The volume is reduced and the pressure is increased.

(3) The vapor or gas is discharged at high pressure.

(4) The machine is returned to its original condition in readiness to repeat the cycle.

At first glance the cycle of a thermal compressor may seem to deviate from this sequence, but it can be shown that each one of these operations is accomplished in the order stated.

To facilitate comparison, the sequence of events comprising the cycle of a reciprocating compressor is tabulated.

(1) Vapor at low pressure is taken into the cylinder. During this operation, the suction valve is open, the discharge valve is closed and the piston is moving away from the cylinder head.

(2) The volume of the vapor is reduced and its pressure in-

creased by closing the suction valve and moving the piston toward the cylinder head.

(3) The vapor is discharged at high pressure by opening the discharge valve and continuing the motion of the piston toward the cylinder head.

(4) The compressor is returned to its original condition by closing the discharge valve and opening the suction valve in readiness to repeat the cycle.

Many substances have been proposed for use in the absorption refrigerating system, some of which have been successful; however, the most widely used refrigerant is ammonia with water employed as the compressing fluid or absorbent. The thermal compressor of a simple ammonia system is a closed tank which is partially filled with water and is provided with pipe connections to the evaporator and to the condenser. Cold-water coils and steam coils inside the tank are provided to alternately cool and heat the water. All air and noncondensable gases must be evacuated before the compressor is ready to operate. Now, with the tank contents at room temperature and the connection to the condenser closed, the evaporator connection is opened and the sequence started.

(1) Ammonia vapor at low pressure enters the tank from the evaporator.

(2) The volume of the vapor is reduced to an insignificant amount when it is absorbed by the cool water. Heat is evolved when ammonia dissolves in water and in order to keep the temperature of the tank contents from rising, it is necessary to circulate water through the cooling coils. At 80° F. and normal atmospheric pressure, water will absorb approximately 1000 times its own volume of ammonia vapor; thus, an extraordinary degree of compression is secured. After the water has become saturated, the connection with the evaporator is closed, the cooling water is cut off and the heating steam turned on. The solubility of ammonia in water decreases as the temperature rises; thus, the heating drives the vapor out of solution. When a sufficient quantity of vapor has been driven out to raise the pressure in the tank to the level prevailing in the condenser, the connecting pipe is opened.

(3) The vapor is discharged at high pressure by continued heating of the solution.

(4) The machine is returned to its original condition by cutting off the supply of steam to the heating coils, closing the condenser

connection, cooling the tank contents and opening the connection to the evaporator in readiness to repeat the cycle.

In effect, the thermal compressor uses a quantity of water which is alternately cooled and heated to secure the effect of the cylinder and moving piston of the mechanical unit. The suction stroke of the piston is duplicated by the tank drawing in a large volume of vapor. The compression stroke is analogous to the reduction of volume by solution in water and the discharge of vapor at high pressure to heating the solution. Mechanical energy is supplied to the piston compressor whereas heat is the form of energy supplied to the thermal compressor.

In actual operation it is impracticable to drive all the ammonia from the solution by heating; thus, in the second step of the cycle the vapor is absorbed in a cool weak solution of ammonia instead of pure water. In order to secure continuous operation and greater efficiency in the large systems, the absorption and cooling take place in one tank which is called the "absorber" and the vapor is driven out of solution by heating in a second vessel which is known as the "generator." The solution is pumped from the absorber, which is connected to the evaporator and is consequently at low pressure, to the generator, which is connected to the condenser and is thus at high pressure. The hot, weak liquor leaving the generator flows through a heat exchanger and is cooled before entering the absorber, whereas the strong cool liquor is pumped counter-current through the exchanger and is thereby heated before entering the generator. After the vapor leaves the generator, it passes through an apparatus known as the rectifier, which separates water from the vapor and permits only dry ammonia to enter the condenser.

A mathematical analysis of any unit of the absorption system may be made by means of weight and energy balances and the relations between temperature, pressure, concentration, and enthalpy of the solution. It is assumed that the frictional resistance to flow in the apparatus is negligible, insulation prevents any accidental heat leakage, and the heating effect of the aqua pump can be disregarded. The temperature of the condenser is usually fixed by the available cooling water supply and this in turn determines its pressure and the pressure prevailing in the generator. Refrigerator temperature determines the pressure in the evaporator which is also the absorber pressure whereas the absorber temperature is limited by the cooling water which is usually the condenser waste. The maximum generator temperature is determined by the pressure of the steam used for heating. The following problem illustrates the principles involved:

An ammonia-water absorption system is to operate under the following conditions:

Evaporator temperature: 0° F.
Absorber temperature: 110° F.
Generator temperature: 250° F.
Condenser temperature: 90° F.

SYMBOLS EMPLOYED IN SOLUTION OF PROBLEM

C denotes specific heat of aqua ammonia.
h_f * is specific enthalpy of anhydrous liquid ammonia.
h_g * is specific enthalpy of anhydrous ammonia vapor.
Q_A denotes heat removed from absorber.
Q_A' denotes heat removed from absorber when an exchanger is used.
Q_C denotes heat removed from condenser.
Q_G denotes heat supplied to generator.
Q_G' denotes heat supplied to generator when an exchanger is used.
Q_S denotes heat of solution of liquid ammonia and water.
Q_X denotes heat transferred from weak to strong liquor in an exchanger.
Subscripts A, C, E, G, and X denote respectively the conditions in absorber, condenser, evaporator, generator and of the strong liquor stream from the heat exchanger.
T_l denotes saturation absolute temperature of anhydrous ammonia at the prevailing pressure.
T_s denotes equilibrium absolute temperature of aqueous ammonia at the prevailing pressure.
x_1 denotes weight fraction of ammonia in strong liquor.
x_2 denotes weight fraction of ammonia in weak liquor.

* In the tables these symbols appear thus: h_f is represented by h; h_g is represented by H.

An approximate analysis may be made upon the assumption that water is not volatilized and thus anhydrous ammonia circulates through the condenser and evaporator. In this case, the condenser pressure is 180.6 psia., corresponding to saturated liquid ammonia at 90° F., and the generator pressure is identical. This allows the concentration x_2 of the weak liquor in the generator to be calculated by Mollier's equation thus:

$$x_2 = 2.146\left(\frac{T_l}{T_s} - 0.656\right)$$

$$x_2 = 2.146(\tfrac{550}{710} - 0.656)$$

$$x_2 = 0.254.$$

The absorber pressure is identical with that in the evaporator, which is 30.4 psia. corresponding to saturated liquid ammonia at 0° F.; hence, the concentration x_1 of the strong liquor is given by the Mollier equation:

$$x_1 = 2.146(\tfrac{460}{570} - 0.656) = 0.324.$$

On the basis of the assumption that only anhydrous ammonia enters the condenser, a weight balance may be set up for the generator. For each pound of vapor driven out of solution, n pounds of strong liquor enters the generator and $n - 1$ pounds of weak liquor leaves; hence,

$$nx_1 = (n - 1)x_2 + 1,$$

and

$$n = \frac{x_2 - 1}{x_2 - x_1} = \frac{0.254 - 1}{0.254 - 0.324} = 10.66 \text{ lbs.}$$

of strong liquor must be circulated per pound of refrigerant.

Generator Process. The Law of Constant Heat Summation, formulated by Hess,* is very helpful in solving the generator and absorber heat balances. It is a specialized form of the First Law of Thermodynamics and declares that the net heat change in a series of processes depends only upon the initial state and the final state. This permits the division of the entire process of absorption or distillation into a series of step processes which may be easily analyzed. Thus, the generator unit receives n pounds of strong liquor at absorber temperature t_A and is supplied the quantity of heat Q_G which causes one pound of ammonia to leave as superheated vapor at the temperature t_G and pressure p_G that prevail in the generator while $n - 1$ pounds of weak liquor are discharged at the temperature T_G.

This may be subdivided into three steps as follows:

(1) The strong liquor is supplied at constant temperature with the quantity of heat Q_S, which causes it to separate into one pound of liquid anhydrous ammonia at t_A and n-1 pounds of weak liquor at t_A.

(2) The liquid ammonia is supplied with the heat energy $h_{g(G)} - h_{f(A)}$, which changes it from liquid at t_A to superheated vapor at t_G and p_G and expels it from the unit.

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* Hess, G. H., *Ann. Physik.*, 2, 1842, Vol. 52, p. 97; *Pogg. Ann.*, 1840, Vol. 50, p. 385.

(3) The weak liquor is now heated from t_A to t_G by absorbing the quantity of heat $(n - 1)\ C\ (t_G - t_A)$.

The sum of the quantities of heat supplied to each of these processes equals the heat input to the generator unit:

$$Q_S + h_{g(G)} - h_{f(A)} + [(n - 1)\ C\ (t_G - t_A)] = Q_G.$$

From Mollier's equation,

$$Q_S = 345\frac{x_1 + x_2}{2} - 400\left(\frac{x_1 + x_2}{2}\right)^2$$

$$Q_S = 66.8 \text{ Btu.}$$

From ammonia chart or table,

$h_{g(G)}$ = enthalpy of superheated vapor at 250° F. and 180.6 psia.

$h_{g(G)} = 736$ Btu. and

$h_{f(A)}$ = enthalpy of liquid at 110° F.

$h_{f(A)} = 167$ Btu.

If the specific heat of aqua ammonia is taken at an average value of $C = 1.05$, then

$$(n - 1)C(t_G - t_A) = (10.66 - 1)1.05(250 - 110) = 1420 \text{ Btu.}$$

Hence, $Q_G = 67 + 736 - 167 + 1420 = 2056$ Btu supplied to generator per pound of refrigerant circulated through the evaporator when all heating of the liquor is accomplished in the generator. If an exchanger is used to transfer heat from the outgoing hot, weak liquor to the incoming cool, strong liquor a considerable saving in energy is possible. Assuming that the strong liquor is heated to 185° F. in a counter-current exchanger, the heat saved is

$$Q_X = nC(t_X - t_A) = 10.66 \times 1.05(185 - 110) = 840 \text{ Btu.}$$

Thus, the net heat required when the exchanger is employed becomes

$$Q_G' = 2055 - 840 = 1215 \text{ Btu.}$$

For either case the refrigerating effect per pound of ammonia is the difference between the enthalpy of saturated vapor at 0° F. and saturated liquid at 90° F.

$$\text{Ref. eff.} = h_{g(E)} - h_{f(C)} = 611.8 - 143.5 = 468.3 \text{ Btu per lb.}$$

The heat to be removed from the condenser is the difference between the enthalpy of superheated vapor at generator temperature and saturated liquid at condenser conditions.

$$Q_C = h_{g(G)} - h_{f(C)} = 736 - 143.5 = 592.5 \text{ Btu per lb.}$$

Absorber Process. The heat removed from the absorber may be determined by dividing the process into steps and applying Hess's Law.

(1) Saturated vapor entering at evaporator temperature t_E is condensed to liquid at absorber temperature t_A.

(2) Weak liquor at the temperature t_G is cooled to absorber temperature t_A.

(3) The two liquids are mixed and the heat of solution is removed.

In the first step the heat removed is the difference between the enthalpy $h_{g(E)}$ of vapor at evaporator conditions and the enthalpy $h_{f(A)}$ of saturated liquid at absorber temperature.

$$Q_{\text{I}} = h_{g(E)} - h_{f(A)} = 611.8 - 167.0 = 446.8 \text{ Btu.}$$

The second step comprises cooling $n - 1$ pounds of weak liquor from T_G to T_A; hence,

$$Q_{\text{II}} = (n - 1)C(t_G - t_A) = 9.66 \times 1.05\ (250 - 110).$$

In the third step the heat of solution must be removed while the liquefied refrigerant and cool weak liquor are mixing:

$$Q_{\text{III}} = 345\,\frac{x_1 + x_2}{2} - 400\left(\frac{x_1 + x_2}{2}\right)^2.$$

Thus, the total heat to be removed in the absorber is the summation of the heat effects in the three steps:

$$Q_A = Q_{\text{I}} + Q_{\text{II}} + Q_{\text{III}}$$

$$Q_A = [h_{g(E)} - h_{f(A)}] + [(n - 1)C(t_G - t_A)] + \left[345\,\frac{x_1 + x_2}{2} - 400\left(\frac{x_1 + x_2}{2}\right)^2\right]$$

$$Q_A = [612 - 167] + [9.66 \times 1.05 \times (250 - 110)] + [(345 \times 0.289) - (400 \times 0.0825)]$$

Q_A = 1932 Btu per pound of refrigerant circulated through the evaporator.

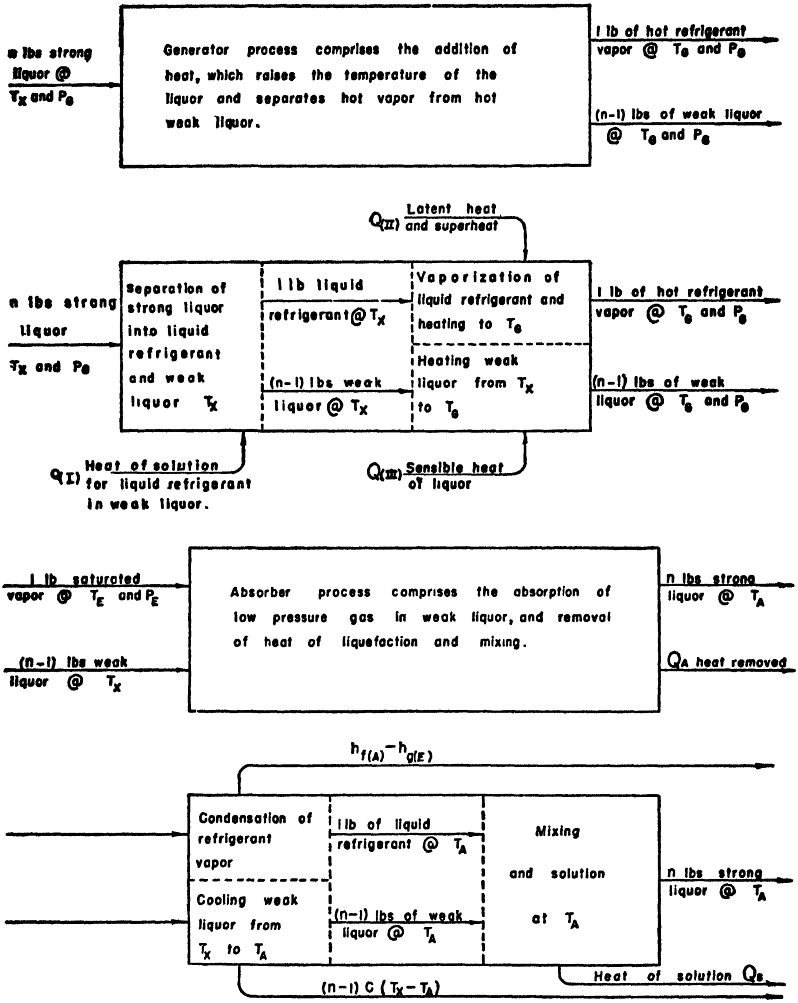
n lbs strong liquor @ T_X and P_G
Generator process comprises the addition of heat, which raises the temperature of the liquor and separates hot vapor from hot weak liquor.
1 lb of hot refrigerant vapor @ T_G and P_G
(n-1) lbs of weak liquor @ T_G and P_G
$Q_{(II)}$ Latent heat and superheat
n lbs strong liquor T_X and P_G
Separation of strong liquor into liquid refrigerant and weak liquor T_X
1 lb liquid refrigerant @ T_X
(n-1) lbs weak liquor @ T_X
Vaporization of liquid refrigerant and heating to T_G
Heating weak liquor from T_X to T_G
1 lb of hot refrigerant vapor @ T_G and P_G
(n-1) lbs of weak liquor @ T_G and P_G
$Q_{(I)}$ Heat of solution for liquid refrigerant in weak liquor.
$Q_{(III)}$ Sensible heat of liquor
1 lb saturated vapor @ T_E and P_E
(n-1) lbs weak liquor @ T_X
Absorber process comprises the absorption of low pressure gas in weak liquor, and removal of heat of liquefaction and mixing.
n lbs strong liquor @ T_A
Q_A heat removed
$h_{f(A)}-h_{g(E)}$
Condensation of refrigerant vapor
Cooling weak liquor from T_X to T_A
1 lb of liquid refrigerant @ T_A
(n-1) lbs of weak liquor @ T_A
Mixing and solution at T_A
n lbs strong liquor @ T_A
$(n-1)\,C\,(T_X-T_A)$
Heat of solution Q_S

FIG. 6-1. Diagrams of Generator Process and Absorber Process, Divided into Steps for the Application of the Law of Constant Heat Summation, as Formulated by Hess.

When a heat exchanger is employed to transfer heat between cool, strong liquor and the hot, weak liquor, the net heat to be removed from the absorber will be decreased by amount exchanged. Thus, if 840 Btu are transferred, the cooling load of the absorber becomes

$$Q_A' = Q_A - 840 = 1932 - 840 = 1092 \text{ Btu.}$$

Commercial absorption machines date back to the inventions of Ferdinand Carré as early as 1850, but the laboratory demonstration of the elementary absorption principle pre-dates this invention several years. An absorption machine of laboratory dimension was set up by Michael Faraday many years before the Carré invention. Most of the absorption machines developed before the Carré machine used sulphuric acid. Carré employed ammonia and water.

The mixture of ammonia gas and water is known to the refrigerating industry as *aqua ammonia.* Aqua ammonia is usually purchased in drums of 750 lbs.

The strength of aqua ammonia is usually measured with the hydrometer in degrees Baumé. As the specific gravity of the ammonia changes with temperature as well as with the amount of ammonia present, the specific gravity is always based on a temperature of 60° F. This means that if hydrometer readings are taken of the aqua ammonia when it is hotter than 60° F. the readings taken will be too low.

TABLE 6–1. SPECIFIC GRAVITY OF AQUA AMMONIA AT 60° F.

PER CENT AMMONIA BY WEIGHT	SPECIFIC GRAVITY AT 60° F.	CORRESPONDING DEGREES BAUMÉ
10	.9598	15.8
12	.9528	16.9
14	.9458	18.0
16	.9390	18.9
18	.9325	20.1
20	.9262	21.2
22	.9194	22.2
24	.9165	22.7
26	.9075	24.2
28	.9015	25.3
30	.8953	26.3
32	.8898	27.3
34	.8842	28.4
36	.8786	29.4

As the aqua ammonia comes in drums and is supplied to the generator it is known as *strong liquor*. After it has been boiled and much of the ammonia gas given off, it is known as *weak liquor*.

Generator. The ammonia generator which replaces the compressor in the absorption system is essentially an aqua ammonia boiler with provision made to draw off the weak liquor at the bottom and for the ammonia vapors distilled off to pass to the rectifier through top openings.

The generator drums may be positioned vertically or horizontally, the more common types being horizontal. To economize in space, the horizontal types are often made up with two and three drums placed above each other, each drum being heated with a steam coil. The main drum bodies, containing the liquid, discharge into a common header passing to the rectifier.

Rectifier. The gas passing off from the boiling ammonia liquid carries with it large quantities of water. Since the water present will condense at a much higher temperature than the ammonia, the gas is passed to the rectifier, which is, in fact, a form of condenser-separator. In the rectifier the gas is cooled sufficiently to condense the surplus water which, in turn, is separated and returned to the generator. Then the cooled ammonia gas is passed on to the ammonia condenser. The cooling of the rectifier is usually done by the strong liquor just as it comes from the ammonia liquor pump.

Rectifiers, like condensers, may be made of any of the several types, but it is most common to find a rectifier made up like a double-tube or a multi-pass condenser.

Exchanger. The exchanger is introduced in the absorption system to conserve both heat and cold. The weak liquor, as it comes from the generator, is very hot. Before it can be readily strengthened in ammonia content again, it must necessarily be cooled. On the other hand, the liquor that has already been strengthened by the introduction of ammonia gas and is on its way to the generator for another boiling, can be heated to reduce the amount of heating necessary in the generator. The hot weak liquor and the cooled strong liquor are passed through an exchanging device similar in all respects to the several forms of condensers previously described. This is known as the exchanger. Like the rectifier, the exchanger is usually a double-tube or a multi-pass type.

TABLE 6-2. PROPERTIES OF AQUA AMMONIA

(Values given in this table are temperatures of boiling point corresponding to indicated pressures and concentration. Thus 14% aqua ammonia solution will boil at 270° F. when the pressure of generator is 120 pounds, absolute)

ABSOLUTE PRESSURE	PERCENTAGES OF AMMONIA BY WEIGHT														GAGE PRESSURE (APPROX.)
	10	12	14	16	18	20	22	24	26	28	30	32	34	36	
20	171	163	155	147	140	132	125	117	110	104	97	90	84	79	5
25	184	175	167	159	151	144	136	129	122	116	109	101	95	89	10
30	195	186	178	169	161	154	146	139	132	125	118	111	104	98	15
35	204	195	187	179	170	163	155	148	140	133	126	120	113	107	20
40	212	203	195	187	178	170	163	155	148	141	134	127	120	114	25
50	227	217	209	201	192	184	176	169	161	154	146	139	132	126	35
60	240	229	221	212	203	195	187	180	172	165	157	150	142	136	45
80	260	249	241	232	223	214	206	198	191	183	175	167	160	153	65
100	276	266	256	247	238	229	221	213	205	197	189	182	175	167	85
120	289	279	270	260	251	242	233	226	218	209	201	194	187	179	115
140	302	292	282	272	263	254	245	237	229	221	212	205	197	190	125
160	313	302	292	283	273	264	255	247	238	230	222	214	206	199	145
180	323	312	302	292	282	273	265	256	248	239	231	222	214	207	165
200	332	321	311	301	292	283	273	265	256	248	239	231	223	214	185

TABLE 6-3. VALUES OF HEAT OF ABSORPTION OF ONE POUND OF AMMONIA IN AQUEOUS AMMONIA

X = Mean concentration
Q = Heat of solution

X	Q	X	Q	X	Q
.150	284.25	.225	247.13	.300	205.50
.155	281.92	.230	244.49	.305	202.59
.160	279.56	.235	241.84	.310	199.61
.165	277.19	.240	239.16	.315	196.64
.170	274.79	.245	236.47	.320	193.64
.175	272.38	.250	233.75	.325	190.63
.180	269.94	.255	231.02	.330	187.59
.185	267.49	.260	228.26	.335	184.54
.190	265.01	.265	225.49	.340	181.46
.195	262.52	.270	222.69	.345	178.37
.200	260.00	.275	219.88		
.205	257.47	.280	217.04		
.210	254.91	.285	214.19		
.215	252.34	.290	211.31		
.220	249.74	.295	208.42		

Absorber. The absorber is introduced in the absorption system to remix the weak liquor and the ammonia vapor. After the weak liquor has been sufficiently cooled after leaving the generator, it is passed on to the absorber. The gaseous vapors of ammonia coming from the evaporator or cooler are introduced into the absorber and the weak liquor absorbs it to the required strength. This, then, produces the strong liquor for the re-charging of the generator.

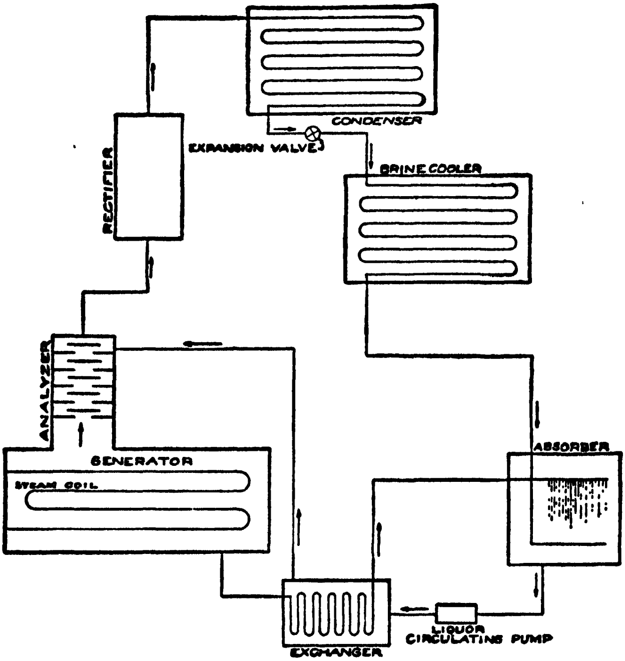

FIG. 6–2. Diagrammatic layout of the absorption system.

With these different terms and devices explained, it will be well to follow through the several cycles found in the absorption system.

Ammonia Gas Cycle. The aqua ammonia is boiled in the generator to the point of driving off the ammonia and some water. It passes to the rectifier where the water is condensed and the ammonia cooled. The water is separated and returned to the generator, but the cooled gas passes on to the condenser where it is condensed and passed on to the receiver. From the receiver it passes through the expansion valve to the cooler. Here it takes up heat and is revaporized.

From the cooler it passes into the absorber to be taken up by the cooled weak liquor. This now makes up the charge of strong liquor which is pumped by the ammonia pump through the rectifier and exchanger to the generator, thus completing the cycle.

Weak Liquor Cycle. When the strong liquor is subjected to high temperature in the generator, the pure water being heavier than the ammonia and the ammonia boiling off at a lower temperature than the water, the weak liquor collects at the bottom of the generator. The incoming strong liquor causes it to leave and pass to the exchanger to be partly cooled; then it is further cooled by passing through a weak liquor cooler. From here it goes to the absorber to take up a new charge of ammonia gas and it becomes strong liquor.

Strong Liquor Cycle. As mentioned under the ammonia gas cycle, the strong liquor, formed in the absorber by the union of ammonia gas and weak liquor, is picked up by the ammonia liquor pump, forced through the rectifier where it is warmed up, then passed to the exchanger where it is heated further. Then it passes to the generator to be heated.

Cooling Water Cycle. When the water is cold, it is common practice to run the water first to the condenser. Here it liquefies the ammonia and comes from the condenser sufficiently cold to be used again at either the absorber or the weak liquor cooler. (On account of the heat produced in the absorber by the chemical combination of the ammonia gas and the weak liquor, cooling coils are passed through the absorber.) The remainder of the condenser water is passed to the weak liquor cooler to lower the temperature of the weak liquor before it goes to the absorber.

In warm climates, where often a suitable supply of cold water is not available, a separate supply is maintained for each of the three. That is, a separate water supply is maintained for condenser, absorber, and weak liquor cooler.

Whether separate water supplies are used or not, in either case the water coming from the three cooling systems may be passed to the sewer discharge, or carried either to cooling towers or cooling spray ponds to be re-used. Whereas some power is used in sending such water through the cooling process of either spray ponds or cooling towers, there are certain advantages. The water used and re-used does not scale so badly, since it has only so much hardness to deposit, and once this is separated the water is practically nonscaling. Further, unless very cheap water is available, it is seldom

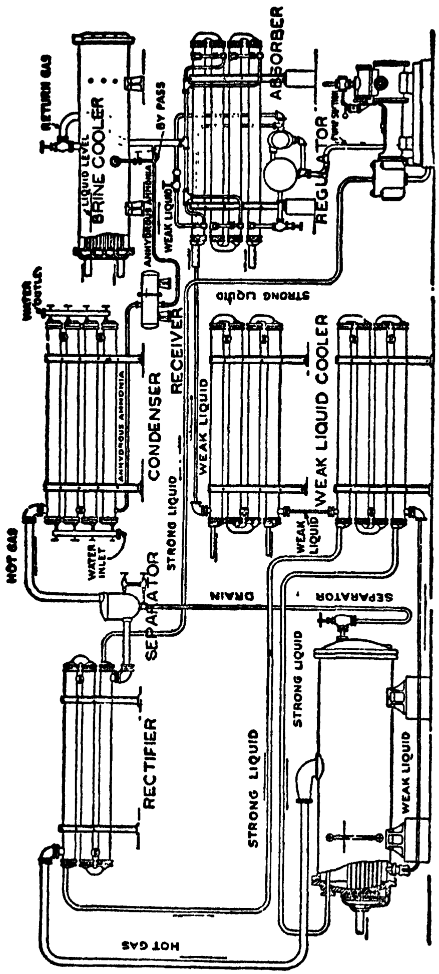

FIG. 6-3. Typical arrangement of equipment for the absorption system.

possible to secure it, either by pumping or by purchase, at as low a cost as by cooling it either by sprays or cooling towers.

Precautions for Operating Absorption Plants. A number of precautions must be taken in the operation of any absorption machine. The following troubles common to the system are given with the probable causes.

Excessive condenser pressures may be caused by:

(1) Insufficient water supply or supply too hot.

(2) Scale or mud on the cooling surfaces.

(3) Noncondensable gases and air collecting in the upper coils of the condenser.

Likewise, excessive absorber pressures may be experienced by:

(1) Insufficient water supply or supply too hot.

(2) Collection of mud or dirt on the cooling surface.

(3) Collection of foul gases and air in the cooling coils.

(4) Weak liquor coming to the absorber at too high a temperature.

(5) Weak liquor coming to the absorber in too strong a percentage of ammonia.

Required high steam pressures in the generator may be caused by:

(1) Muddy or dirty generator heating coil surfaces.

(2) Air with other gases in the steam coil.

(3) Water in the steam coils due to improper venting and draining.

(4) Ammonia charge too weak.

(5) Ammonia pump not pumping sufficient ammonia to use up heat of the steam.

Operating factors and conditions that will cause low production from the absorption unit are as follows:

(1) Low water supply.
(2) Water too hot.
(3) Low steam-generator pressure.
(4) Too wet steam in generator.
(5) Low ammonia charge.
(6) Weak ammonia charge.
(7) Low-pressure system in need of purging.
(8) Condenser in need of purging.
(9) Receiver in need of purging.
(10) Muddy or dirty condenser surfaces.
(11) Ammonia leaks.
(12) Ammonia too wet.
(13) Ammonia pump slip too high.
(14) Poorly designed brine system.

Typical Operating Conditions. If it is assumed that the generator is operating on 20 lbs. gage pressure in the steam coils, the aqua ammonia might reach a temperature of 240° F., boiling violently and carrying with it a certain amount of water vapor and some finely divided particles of liquid ammonia. As usually designed, an analyzer is attached directly to the discharge of the generator. Hot strong liquor comes directly from the exchanger to the analyzer and pours down from pan to pan in the analyzer, giving a falling spray of hot ammonia liquor through which the gas from the generator must rise and pass.

The temperature of the hot liquor coming from the exchanger is below that of the vapors rising from the generator. The strong liquor is sufficiently lower in temperature than the rising vapor from the generator to condense most of the water vapor, thus leaving the ammonia vapor to pass on to the rectifier.

The resultant action of the analyzer has been, therefore, (1) to heat up the incoming liquor as it mingles with the hot vapors and discharges it into the generator at a strength of 26 to 29%; (2) to separate out some excess water vapor and return it to the generator; (3) to cool the vapors from the generator to some extent, thus reducing the amount of heat that must be removed later in the rectifier and condenser.

At the bottom of the generator there has been an opposite process going on. The strong liquor, in the process of boiling, becomes higher in its percentage of water at the bottom of the generator and, thus, lower in its percentage of ammonia. This is due to the higher specific gravity and the higher boiling point of the water as compared with ammonia. The actual percentage of ammonia in the generator bottom may be down as low as 20 to 23% as compared with rich ammonia liquor coming into the generator from the analyzer at 26 to 29%.

At any one time there will be in the generator, therefore, weak liquor at the bottom at from 20 to 23% ammonia, strong liquor entering from the analyzer at from 26 to 29% ammonia, and ammonia vapor passing off to the analyzer containing from 10 to 15% water vapor. The analyzer condenses and returns some of the water vapor, and the remaining gas passes on to the rectifier with its water percentage reduced to, probably, 5 to 8%.

The rectifier is the final water-separating device used before the ammonia gas passes to the condenser. The rectifier is really a condenser arranged so that the strong liquor coming directly from the absorber at, probably, 120° F. is passed through the tubes of the rectifier, and the ammonia vapor with its percentage of water is cooled below the boiling point of the water in the space surrounding the tubes. This condenses the water, but leaves the ammonia vapor, which has been cooled to probably 145° F., to pass on to the condenser. The water condensed is trapped back to the generator. The strong liquor, which has been heated in the rectifier to probably 155° F., passes on to the exchanger.

From the rectifier, the gas, which is practically 100% ammonia, passes on to the condenser, receiver, expansion valve, and cooler. The path of the ammonia for this part of the absorption system is the same as in the compression system. In coming through the cooler, the liquid ammonia boils as it takes up heat from the surrounding brine or air, and rises back up to probably 24° F. It passes on to the absorber from the cooler.

It would be well to consider what is now required. Weak ammonia liquor was left back in the generator at 240° F. and reduced to 20 to 23% ammonia. This weak liquor must now be reconcentrated with the gaseous ammonia coming from the cooler. But for this weak liquor to absorb a large amount of ammonia gas it must first be cooled as far as possible.

On the other hand, once the reconcentration takes place it is desirable to heat up the newly created strong liquor as far as possible before returning it to the generator to be boiled.

To meet this condition, the weak liquor is brought through the exchanger and through the weak liquor cooler to the absorber. Its temperature is reduced from 240° F. at the generator to probably 100° F. as it comes from the cooler.

In the absorber the ammonia gas is bubbled up through this cold weak liquor. The weak liquor absorbs many times its own volume of ammonia and is restored to probably 26 to 29% strength.

The liquor pump picks it up at this point and forces it through the rectifier where it heats up to probably 155° F. by cooling the weak liquor coming from the generator and analyzer. It then passes on to the exchanger where it heats up to probably 200° F. by cooling the weak liquor on its way from the generator to the weak liquor cooler, and from the exchanger it returns to the analyzer to again start on its cycle of heat exchange.

TABLES AND CHARTS OF THE THERMODYNAMIC PROPERTIES OF AQUA AMMONIA

A more nearly exact analysis of the operation of the ammonia absorption system may be made with the aid of tables and charts which give the thermodynamic properties of mixtures of water and ammonia. Among several which have been published, the table prepared by Stickney and herewith reproduced as Table 6–4 is convenient to employ. Its use is illustrated by the solution of the following problem.

Problem. The generator of an ammonia absorption system operates at 250° F. and 180 lbs. gage pressure. (a) What is the fraction of ammonia contained in the discharged weak liquor and in the hot vapor passing to the rectifier? (b) What are the corresponding enthalpies in Btu per pound?

Solution. (a) Find the column headed 250° F. and run down the column of figures under x to the line marked 180 lbs. per sq. in. gage. Here is found for the liquid the figure 0.269 and for the vapor the figure 0.871, which indicates that the liquid contains 0.269 of its weight of ammonia in solution and the vapor is 0.871 by weight of ammonia.

(b) The values of enthalpy are found in the column of figures under h on the 180 lbs. per sq. in. line. For the liquid the enthalpy is 171 Btu per lb. and for the vapor it is 792 Btu per lb.

This problem may also be solved by means of the chart Table 6–4 which has been prepared from Stickney's table.

Find the heavy solid line marked 250° in the upper right corner of the chart. Follow this to its intersection with the dashed line marked 180 lbs. per sq. in. Read, on the chart network, the concentration 0.268 lb. of ammonia per pound of liquid and the enthalpy 170 Btu per lb. of liquid.

The assumption that water vapor is not volatilized along with ammonia is approximately true only at rather low temperatures. Since it may be assumed that the boiling solution in the generator is weak liquor, the vapor produced from this liquor contains a considerable fraction of water vapor which must be removed before entering the condenser. The simplest method is to cool the vapor stream sufficiently to condense the water vapor and return the condensate to the generator. However, this liquid is saturated with ammonia at the prevailing temperature and pressure, so that a very large fraction of refrigerant is returned to the generator, where its reheating and vaporization require extra heat. To avoid some of this waste, the vapor stream may be partially cooled by the strong liquor flowing to the generator and this quantity of heat is returned to the generator. Further cooling with water is necessary to secure ammonia vapor of high purity which is essential for the production of very low temperature.

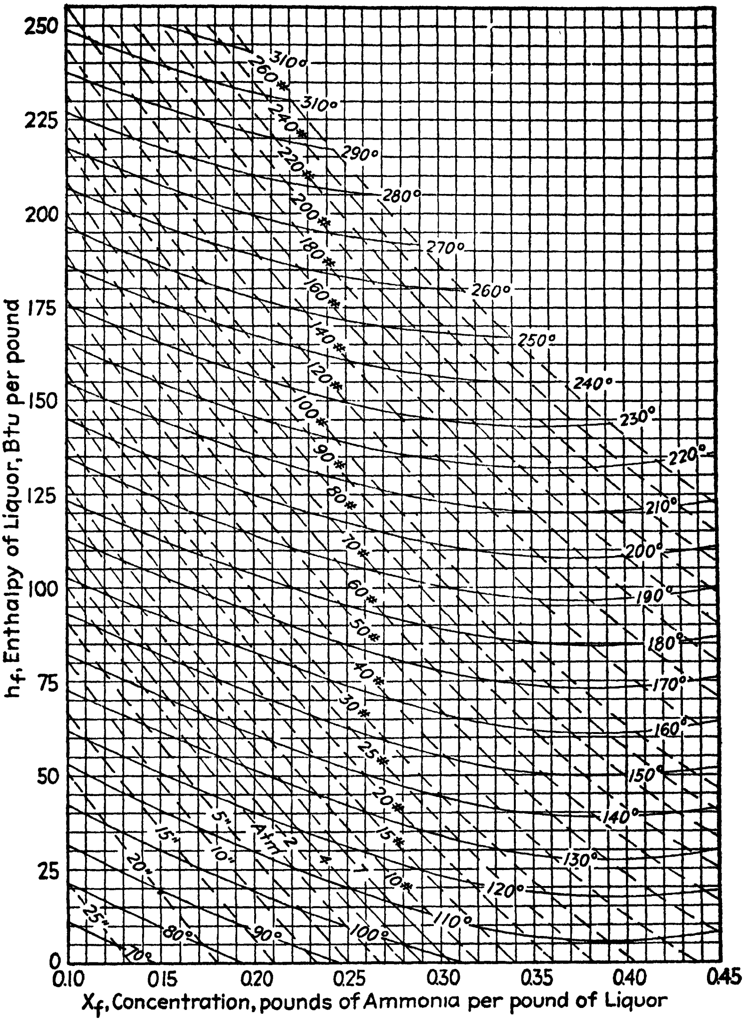

Fig. 6-4. Thermodynamic properties of aqua ammonia under conditions encountered in generator and absorber. Indicated pressures are gage in pounds per square inch or in inches of mercury vacuum.

The generator and its auxiliaries, the analyzer and rectifier, comprise a fractional distilling apparatus. Older machines employed the principle of cooling the vapor in steps, first with strong liquor and finally with water, removing the condensed liquid from each step and returning it to the generator. Modern units return condensed liquid counter-current to the vapor stream in an apparatus which insures intimate mixing, so that the heat given up by condensing water vapor may evaporate a portion of the ammonia from the returning liquid. This may be considered as a series of stills, each one heated by vapor from the preceding unit and receiving liquid by gravity flow from the next unit in the series. The final unit discharges vapor to the condenser and receives a portion of the condensate as its liquid feed stream. Each unit in the series operates at a slightly lower temperature than the preceding one and, except for radiation losses, all heat is removed from the vapor stream at its lowest temperature. The minimum waste of heat is attained when the rectifier returns the absorbent to the generator saturated with refrigerant at the generator temperature and pressure. Thus, the heat energy supplied to the generator is permitted to do the maximum possible work in separating the absorbent from the refrigerant.

ANALYSIS OF THE OPERATION OF AN AMMONIA ABSORPTION SYSTEM, EQUIPPED WITH RECTIFIER, HEAT EXCHANGER AND WEAK AQUA COOLER

For the computations of the problem discussed below Table 6–4 and chart Figure 6–5 are used.

An ammonia absorption system equipped with rectifier, heat exchanger and weak aqua cooler is to operate under the following conditions:

Evaporator temperature: 0° F.
Absorber temperature: 110° F.
Generator temperature: 250° F.
Condenser temperature: 90° F.

The rectifier is assumed to function without losses of any nature. Strong liquor leaves the heat exchanger at 185° F., and the weak liquor is cooled to 110° F. in a weak aqua cooler. It is assumed that fluid flow is frictionless, that the aqua pump does not increase the enthalpy of the weak liquor by an appreciable amount and that radiation losses are negligible.

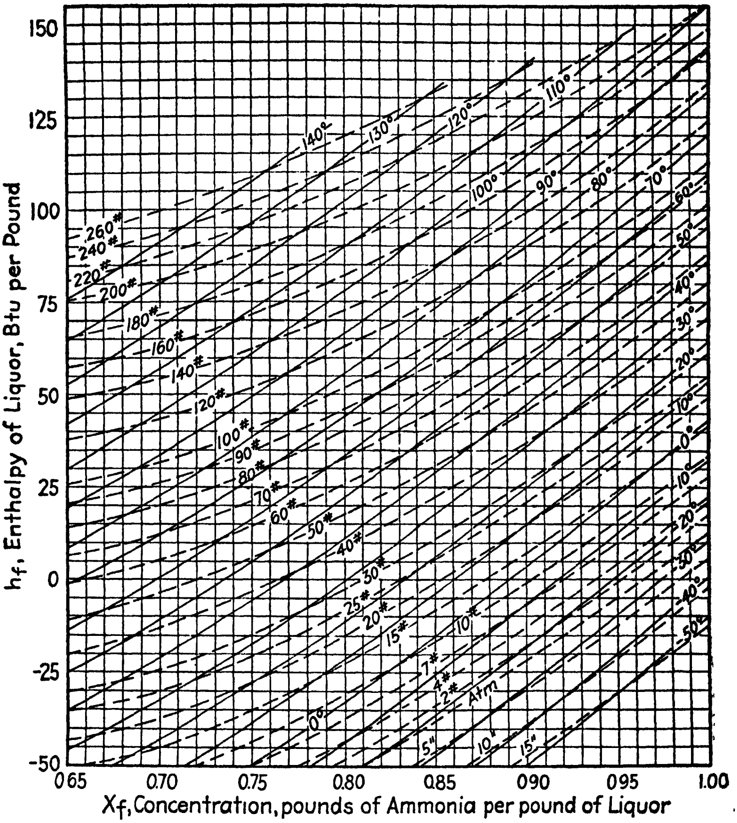

FIG. 6–5. Thermodynamic properties of aqua ammonia under conditions prevailing in evaporator pressure. Given in pounds per square inch gage. Pressure given in pounds per square inch gage.

Determine:

(1) The weight of strong liquor circulated per pound of liquid supplied to the evaporator.

(2) Heat input to generator.

(3) Refrigerating effect.

(4) Heat removed from weak aqua cooler.

(5) Heat removed from absorber.

(6) Heat removed from condenser.

Symbols Used in the Solution of This Problem

h_f = enthalpy of liquid under specified conditions.
h_g = enthalpy of vapor under specified conditions.

The subscripts (A), (C), (E), and (G) denote, respectively, under conditions in the absorber, condenser, evaporator and generator. Thus,

$h_{f(A)}$ = the enthalpy of liquid under absorber conditions.
$h_{f(X)}$ = enthalpy of strong liquor leaving heat exchanger.
$h_{f(Y)}$ = enthalpy of weak liquor leaving heat exchanger.
$h_{f(Z)}$ = enthalpy of weak liquor leaving aqua cooler.
n = weight of strong liquor per pound of liquid supplied to the evaporator.
p = weight of vapor leaving evaporator per pound of liquid entering.
Q_A = heat removed from absorber.
Q_C = heat removed from condenser.
Q_G = heat supplied to generator.
R = weight of weak liquor returning to generator from rectifier.
x_f = concentration of liquid, pounds of ammonia per pound of liquid.
x_g = concentration of vapor, pounds of ammonia per pound of vapor.

There are many possible solutions of this problem and the most desirable one, for a particular installation, must take economic factors into consideration. In general, the principal operating costs of an absorption refrigeration system are heat and cooling water. Thus, the operating conditions should be balanced to secure the minimum total cost. If the unit cost of heat and cooling water are known, several solutions of the problem are made, each based upon arbitrary assumptions of certain unspecified operating conditions, and the total costs are computed. Then the most economical operating conditions are selected for the actual system.

The conditions which are given in the statement of this problem do not fix pressures in any part of the system; consequently, it is necessary to assume the pressure in some unit and complete the solution of the problem upon this basis.

It is usually desirable to have the strong liquor in the absorber at the highest possible concentration, since this will require a smaller heat input to the generator. However, the concentration of liquid in the absorber is limited by the pressure in this unit which is also the pressure prevailing in the evaporator. Since the evaporator temperature is 0° F., the maximum possible pressure is that corresponding to saturated anhydrous ammonia, which is 15.7 lbs. per sq. in. Reference to Table 6–4 shows that at 0° F., the liquid has a concentration of 0.968 ammonia at 15 lbs. per sq. in. and is 0.819 ammonia at 10 lbs. per sq. in. However, a rectifier does not consistently deliver anhydrous ammonia; hence, some allowance must be made for small amounts of water in the liquid supplied to the expansion valve of the evaporator. Assuming that the rectifier delivers vapor of 0.990 concentration, it is safe to set the evaporator pressure at 15 lbs. per sq. in. and this fixes the absorber pressure at the same value.

On this basis, reference to the table shows that with the absorber at 110° F. and 15 lbs. per sq. in., the concentration of strong liquor is $x_{f(A)} = 0.320$, and its enthalpy is $h_{f(A)} = 9$ Btu per lb.

Now it is possible to calculate the pressure in the condenser, which is that prevailing throughout the high side comprising the generator, the rectifier and the condenser. Vapor at $x_{g(C)} = 0.990$ is condensed at 90° F. and the pressure 164 lbs. per sq. in. may be estimated from the chart or determined by interpolation from the table.

The generator, operating at 250° F. and 164 lbs. per sq. in., will discharge hot, weak liquor at equilibrium concentration, which is determined by means of the chart to be $x_{f(G)} = 0.253$ and $h_{f(G)} = 172$, while the vapor supplied to the rectifier is at $x_{g(G)} = 0.857$ and $h_{g(G)} = 798$.

(a) With the known concentrations of strong and weak liquors and of the liquid supplied to the evaporator, it is possible to set up an ammonia balance about the high side and to determine the weight of strong liquor circulated per pound of condenser discharge. Let n represent pounds of strong liquor entering; then $n - 1$ pounds of weak liquor and one pound of condensed liquid are discharged. Thus

$$(n)x_{f(A)} = (n - 1)x_{f(G)} + x_{f(C)} =$$
$$(n)0.320 = (n - 1)0.253 + 0.990.$$

Then, $n = 11$ lbs. strong liquor per pound of liquid supplied to evaporator.

(b) An ammonia balance about the rectifier and condenser will determine the vapor to be supplied to the rectifier. Let $1 + R$ pounds of hot vapor be supplied by the generator; then the rectifier returns R pounds of hot weak liquor to the generator and the condenser discharges one pound of liquid to the evaporator. Thus,

$$(1 + R)x_{g(G)} = (R)x_{f(G)} + x_{f(C)}$$
$$(1 + R)0.857 = (R)0.253 + 0.990$$
$$R = 0.22,$$

and $1 + R = 1.22$ lbs. of vapor supplied by the generator per pound of liquid delivered to the evaporator.

Now the heat supplied to the generator may be calculated by means of an energy balance. The generator receives n pounds of strong liquor at 185° F. from the heat exchanger and R pounds of weak liquor at 250° F. from the rectifier. Simultaneously, it discharges $n - 1$ pounds of weak liquor at 250° F. and $1 + R$ pounds of vapor at 250° F. The heat supplied to the generator is the difference between the enthalpy of the leaving streams and that of the entering streams. Thus,

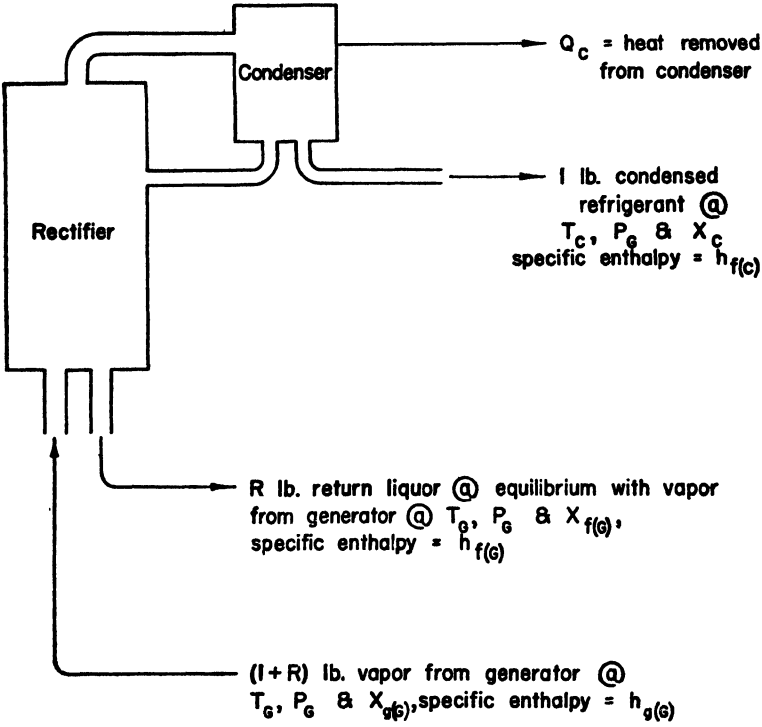
Condenser
Q_C = heat removed from condenser
1 lb. condensed refrigerant @ T_C, P_G & X_C specific enthalpy = $h_{f(c)}$
Rectifier
R lb. return liquor @ equilibrium with vapor from generator @ T_G, P_G & $X_{f(G)}$, specific enthalpy = $h_{f(G)}$
(1 + R) lb. vapor from generator @ T_G, P_G & $X_{g(G)}$, specific enthalpy = $h_{g(G)}$

FIG. 6–6. Schematic diagram of Rectifier Unit.

$$Q_G = (n - 1)h_{f(G)} + (1 + R)h_{g(G)} - nh_{f(X)} - Rh_{f(G)}$$

$$Q_G = (n - 1 - R)h_{f(G)} + (1 + R)h_{g(G)} - (n)h_{f(X)}$$

$$Q_G = (11 - 1 - 0.22)172 + (1.22)798 - (11)93$$

Q_G = 1633 Btu per lb. of liquid supplied to evaporator.

(c) The refrigerating effect may be computed by means of an ammonia balance and an energy balance around the expansion valve and evaporator. One pound of liquid, 164 lbs. per sq. in., 90° F., $x_{f(C)} = 0.990$ and $h_{f(C)} = 141$, flows through the valve into the evaporator. Here the portion p is converted to vapor of $x_{g(E)} = 0.999$, but the remaining water is in liquid form saturated with ammonia at 15 lbs. per sq. in., 0° F. and $x_{f(E)} = 0.968$. This unevaporated small portion $1 - p$ is returned to the absorber along with the vapor stream; thus,

$$x_{f(C)} = px_{g(E)} + (1 - p)x_{f(E)}$$

$$0.990 = (p)0.999 + (1 - p)0.968$$

$$p = 0.710.$$

The refrigerating effect is the difference between the enthalpy of the leaving stream and that of the entering stream

$$Q_{\text{Ref. eff.}} = ph_{g(E)} + (1 - p)h_{f(E)} - h_{f(C)}$$

$$Q_{\text{Ref. eff.}} = (0.71)613 + (1 - 0.71)30 - 141$$

$$Q_{\text{Ref. eff.}} = 303 \text{ Btu per lb. of liquid supplied to evaporator.}$$

The enthalpy of the weak liquor discharged from the heat exchanger may be determined by an energy balance around this unit. The entering streams are n pounds of strong liquor at $h_{f(A)}$ and $n - 1$ pounds of weak liquor at $h_{f(G)}$ while the leaving streams are n pounds of strong liquor at $h_{f(X)}$ and $n - 1$ pounds of weak liquor at $h_{f(Y)}$. Equating the entering and leaving enthalpies,

$$nh_{f(A)} + (n - 1)h_{f(G)} = nh_{f(X)} + (n - 1)h_{f(Y)}$$

$$h_{f(Y)} = h_{f(G)} + \frac{n}{n - 1}(h_{f(A)} - h_{f(X)})$$

$$h_{f(Y)} = 172 + \tfrac{11}{10}(9 - 93) = 80 \text{ Btu per lb.}$$

By reference to the chart Figure 6–4 the temperature of liquid at $x_f = 0.253$ and $h_f = 80$ is determined to be 167° F.

(d) The weak liquor leaving the heat exchanger is passed through a second heat exchanger, the weak aqua cooler, which is cooled by water, and its temperature is reduced to that prevailing in the absorber. The heat removed in this unit is the difference between the entering and leaving enthalpies:

$$Q_{\text{Cooler}} = (n - 1)(h_{f(Y)} - h_{f(Z)})$$

$$Q_{\text{Cooler}} = 10(80 - 20) = 600 \text{ Btu.}$$

(e) In the absorber, the cooled weak liquor stream is mixed with the stream of cold vapor and liquid from the evaporator and solution occurs. Heat is evolved and the absorber must be equipped with cooling coils to maintain a constant temperature. The heat removed is the difference between the enthalpies of the entering and leaving streams:

$$Q_{(A)} = (n - 1)h_{f(Z)} + ph_{g(E)} + (1 - p)h_{f(E)} - nh_{f(A)}$$

$$Q_{(A)} = (10)20 + (0.71)613 + (1 - 0.71)30 - (11)9$$

$$Q_{(A)} = 545 \text{ Btu.}$$

(f) The condenser-rectifier unit receives $1 + R$ pounds of vapor at $h_{g(G)} = 798$ and discharges one pound of condensate at $h_{f(C)} = 141$ and R pounds of hot weak liquor at $h_{f(G)} = 172$. The heat removed is thus the difference between the enthalpies of the entering and leaving streams:

$$Q_{(C)} = (1 + R)h_{g(G)} - h_{f(C)} - Rh_{f(G)}$$

$$Q_{(C)} = (1 + 0.22)798 - 141 - (0.22)172$$

$$Q_{(C)} = 795 \text{ Btu per lb. of liquid supplied to evaporator.}$$

A check upon the accuracy of this solution is provided by the fact that the total energy entering the system is equal to the total energy leaving.

ENTERING ENERGY

Heat to generator	1633 Btu
Heat to evaporator (refrigerating effect)	303 Btu
Total	1936 Btu

LEAVING ENERGY

Heat from absorber	545 Btu
Heat from weak aqua cooler	600 Btu
Heat from condenser	795 Btu
Total	1940 Btu

The discrepancy is explained by the fact that fractions of one Btu have been rounded off throughout the computation.

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SECTION VII

SECONDARY REFRIGERANTS

A secondary refrigerant is a substance which transfers heat by convection and conduction at low temperatures without the agency of other sources of energy. This is in contradistinction to a primary refrigerant which transfers heat by the agency of energy supplied from an external source. Included in this classification are brines and other liquids which remain fluid at the required low temperatures. Secondary refrigerants are employed when the direct expansion of primary refrigerant in the chilled space is undesirable.

DISADVANTAGES OF DIRECT EXPANSION SYSTEM

The disadvantages of the direct expansion system should not be overlooked. First, any leak that might occur in the direct expansion coils will discharge directly into the refrigerator, and, if the material in storage is not in sealed tins or cases, the refrigerant odor will be immediately absorbed by the products in storage.

Second, the direct expansion system requires a large amount of high-pressure refrigerant piping and fittings. Consequently, the loss of refrigerant in such a system may be excessively high. This disadvantage is most seriously experienced in plants where the refrigerators must be reached by long lines installed either underground or in obscure passageways.

Third, the direct expansion system has no hold-over capacity. When the compressor stops there is no reserve of cooling medium that can be pumped to coils to maintain the desired temperature.

BRINE DISTRIBUTION SYSTEM

The brine distribution system is used most extensively for ice-making and for long-distance transfer of "cold." In general, it consists of submerging the primary refrigerant piping beneath the brine, cooling this brine to the desired point, then either circulating it through pipes in the room where refrigeration is desired or cooling the materials in cans, or drums, submerged in the brine.

Brine Coolers. In ice-making plants, the brine cooler is usually built up of coils of pipe arranged in vertical rows between each row of ice cans.

In some ice plants a shell-and-tube cooler, built practically like a return tubular boiler shell, is used. The refrigerant is expanded into the inside of the shell and the brine pumped through the tubes.

For cold-room work, either a double-pipe coil or a shell-and-tube brine cooler is used.

In the double-pipe coil the brine is circulated through the inner pipe and the refrigerant through the outer tubes.

The shell-and-tube coolers used for cold rooms are generally of the multipass design, the brine passing back and forth through the several passes while the refrigerant occupies the space between the coils.

Heat Transfer in Brine Coolers. Brine coolers necessarily involve two steps in the cooling process whereas the direct system entails only one. The brine must be first cooled by the refrigerant; then the brine will, in turn, cool the refrigerator. These two exchanges must necessarily require a greater difference of temperature between the refrigerant and the ultimate refrigerator than would the one exchange of the direct expansion system.

This greater difference of temperature requires that lower suction pressures shall be maintained for the same degree of cooling when the indirect system is used, and lower suction pressures necessarily require a greater horsepower input per ton of refrigeration produced.

Fortunately, for the development of indirect systems, the great improvement in brine-cooling equipment has reduced this margin to a minimum. Brine coolers are now available that are sold on a guarantee of only 2° F. difference in temperature between the brine and boiling refrigerant. Whereas the extra cost of rapid circulation of the brine in such systems must be charged to the system, it, nevertheless, has reduced the wide gap in horsepower requirements between the direct and indirect expansion methods of refrigerating rooms.

For central station refrigeration, the brine circulation method has been found to be very satisfactory. The distribution of refrigerant through long pipe lines has never been looked upon with great favor due to hazard involved in leaks from the high-pressure refrigerant lines. But relatively low pressures can be employed when brine is the cold-carrying agent, and a leak might be of considerable magnitude without causing undue damage since the brine is relatively cheap and practically odorless.

The tanks used for the brine can be made of steel, concrete, or wood. In any case, they should be amply insulated with six to twelve inches of well-built-up cork-board casing, or its equivalent, to reduce the loss of heat through the walls.

In ice-making, the depth of the tanks is usually only a few inches more than the length of the ice pans. The circulation arrangement for the brine through the can nests is always a point of considerable argument, but it generally reduces itself down to the design that will give all of the cans an equal chance to cool down and not permit the brine to short-circuit around any groups of cans at the expense of other parts of the system.

DIRECT EXPANSION SYSTEM WITH HOLDOVER TANKS

This is really a combination brine and direct expansion system. One of the principal disadvantages of the direct expansion system is that there is no appreciable accumulation of "cold" in the room or box, and in the event of a shutdown for a short period the temperature will rise as the warm air enters the insulated walls and passageways.

The installation of holdover tanks is one of the methods adopted to meet this condition. A tank of strong brine is placed within the room, and a portion of the cooling coils are submerged beneath the surface of the brine solution. The "cold" accumulated by the holdover tank will be dependent upon (1) strength of the brine, (2) amount of brine cooled. For long shutdown periods, then, a much larger tank will be needed than for relatively short periods.

Either sodium chloride or calcium chloride brines are suitable.

DIRECT EXPANSION SYSTEM WITH CONGEALING TANKS

In many of its characteristics the congealing tank resembles the holdover tank. In operation, however, it is somewhat different.

In the holdover tank, the brine is maintained in an unfrozen state, and the *holdover* is dependent upon the heat of the liquid of the brine. But in the congealing tank, the strong brine is replaced by a weak brine, preferably of calcium chloride. Part of the coils of refrigerant are submerged as in the holdover tank, and temperatures are maintained that will freeze the weak solution of brine either in part or in total.

With this arrangement, the machine can be shut down for a considerable period since there has been stored up a considerable quantity of "cold" due to the latent heat of fusion of the brine. The distinct advantage of this method of holding temperatures is that the temperature of the brine remains nearly constant during the entire melting period.

The disadvantage in sodium chloride brine for this service is that salt and ice form cryo-hydrate when frozen together, and this is very hard to re-dissolve even on melting. On the other hand, calcium chloride re-enters into solution very readily when melting takes place.

BRINE SPRAY SYSTEM

In the brine spray system, the cooled brine is sprayed into a current of air, the air then being carried to the section to be cooled.

The advantages of such a system are:

(1) Defrosting is eliminated.

(2) A high rate of heat transfer is possible.

(3) There is a small difference of temperature between the brine and room, thus raising the suction pressure.

(4) Practically no space is required in the refrigerator room for the cooling system.

The disadvantages are:

(1) Close humidity control is not as readily effected as with other cooling systems.

(2) The brine sprayed picks up a small amount of moisture from the air due to the lowering of the temperature. This tends to dilute the brine, and provision must be made to either drive off this excess water or to add the necessary brine salts to raise the strength to the required concentration.

Most spray systems require an auxiliary fan to circulate the air. A recent design has been developed to entrain the warm air in a spray head near the top of the room, then release the entrained air near the room floor while the brine passes on to the brine pumps.

Application of Spray Systems. The spray system has been used extensively in packing house operation for the cooling of meats, in cold storage, and in building cooling where very close humidity regulation is not essential. For egg storage and similar work, its application is still experimental.

What Brines to Use in Spray Cooling. For high-temperature storage of 35° F. or above, very weak sodium chloride brine or tap water is satisfactory. For low-temperature work, either sodium chloride or calcium chloride brine is more generally used, with preference given to sodium chloride where unsealed foodstuffs are stored.

CHARACTERISTICS OF BRINES

When a small quantity of one substance is dissolved in another, the resulting solution has a freezing point which is lower than that of the second substance. As more of the first substance is dissolved the freezing point is further depressed until a minimum freezing temperature is attained. This is called the eutectic point or temperature and the composition of the solution is known as the eutectic. Any further addition of the substance to the solution will not lower its freezing point; instead when the temperature is lowered to the eutectic point the extra added substance will solidify or pass out of solution and the remaining liquid will have the eutectic composition. If the temperature is lowered beyond the eutectic point, the entire mixture will freeze solid.

This behavior of solutions is shown by Figure 7–1 which applies to mixtures of common salt and water. In this graph the horizontal scale shows the percentage of salt present and the vertical scale indicates temperature in degrees F. If a 10% solution is cooled, its freezing point is 20.2° F., which is indicated by point *A* on the graph. On cooling this solution below 20.2° F., a portion of the water separates as ice and the liquid becomes more concentrated as a result of this removal of water. As the mixture is cooled further, along the dotted line *AB*, more and more water is removed as ice and the solution becomes progressively stronger until the eutectic temperature −6.0° F. is reached. Any further cooling causes the mixture to solidify completely and it is then 90% ice and 10% solid salt. If a solution containing 23.3% of salt, the eutectic composition, is chilled, it does not change until −6.0° is attained, but any further cooling causes it to solidify completely. Solutions containing more salt than the eutectic will separate out solid salt when cooled below their freezing points.

Thus a solution of 25% salt and 75% water has a freezing point of 14.0° F., designated by point *C* on the graph. When this solution is cooled along the line *CB*, it partially freezes or loses solid salt and the liquid becomes weaker until the eutectic temperature is attained. Any further chilling will now cause the entire mass to solidify. Reference to Figures 7–2 to 7–4 will reveal the general similarity between them.

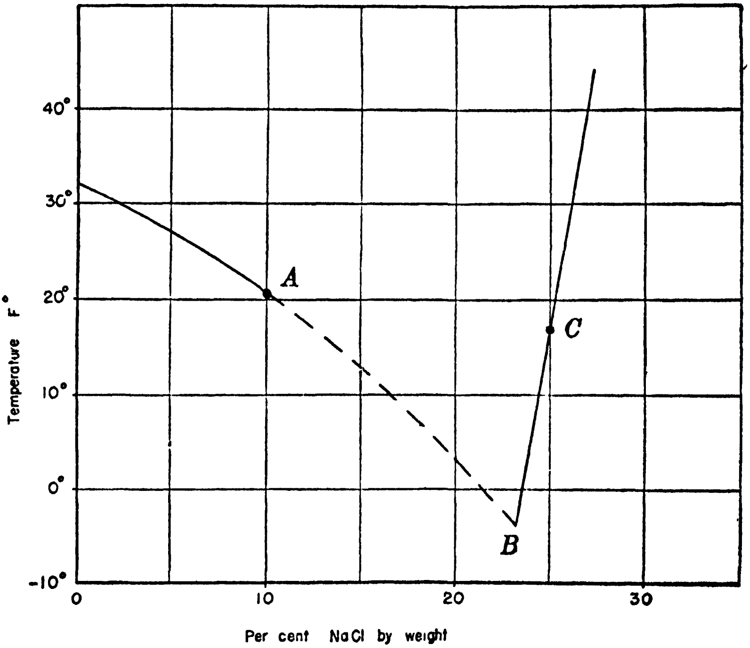

Fig. 7–1. Relation of concentrations of sodium chloride brines to freezing points of brines.

This behavior is characteristic of any mixture, in that only one composition exists which has the lowest freezing point. The eutectic temperature and eutectic composition are entirely dependent upon the particular substances in the mixture. In particular, when a solution containing two substances is chilled, the substance which is present in excess of the eutectic composition will separate or "freeze out." Thus it may be seen that a brine to be used for refrigeration work can be too strong.

REFRIGERATING BRINES

The characteristics which are desirable in a brine for refrigerating purposes are as follows:

(1) Satisfactory heat transfer characteristics, including large specific heat, good thermal conductivity and required freezing temperature.

(2) Low viscosity is desirable to avoid large power expenditure for circulation.

(3) Should not attack or corrode materials of construction.

(4) Incombustible.

(5) Low in first cost and readily available.

(6) Odorless.

There have been an enormous number of substances proposed for use as refrigeration brines but in general the water solutions of inorganic salts are used for all purposes except where very low temperatures are necessary. For extremely low temperatures alcohols in aqueous solution and hydrocarbons are utilized. Common salt, calcium chloride and magnesium chloride have been the most widely used substances for the preparation of refrigerating brines.

SODIUM CHLORIDE BRINES

Water solutions of sodium chloride, frequently known as "sodium brines," are very widely employed, since common salt is very low in price and is readily procured. The eutectic temperature in water solution is $-6.0°$ F., which covers the range of ice-making and of the majority of cold storage installations. Specific heat and thermal conductivity are high and the viscosity is low enough to minimize the power required for circulation. In packing houses and food plants where brine may accidentally leak or spill upon foodstuffs, it is desirable to use salt brine instead of the unpleasant tasting calcium or magnesium chloride brines. Commercial common salt is frequently acid in character, because of the presence of impurities. Careful neutralization of the brine is thus necessary to prevent corrosion of the brine system and piping.

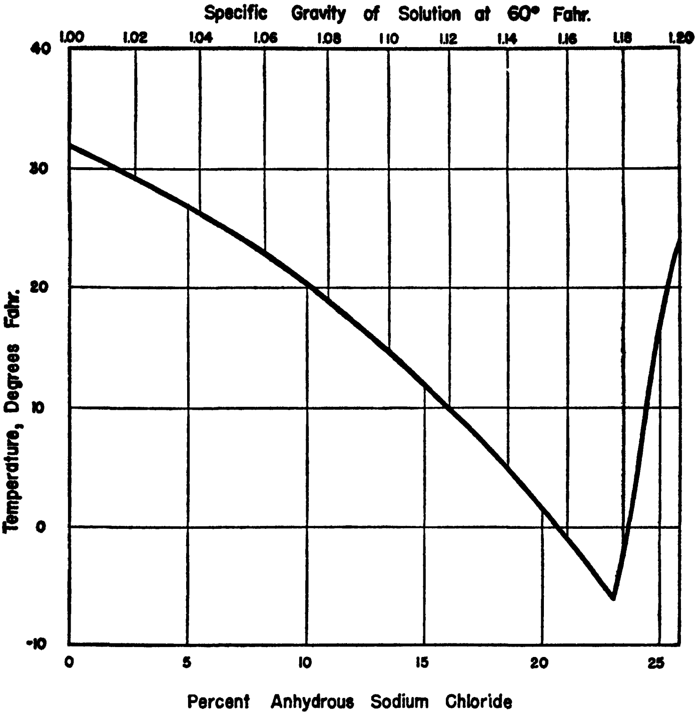

FIG. 7–2. Graph showing freezing point, specific gravity, and percentage composition of sodium chloride brines.

CALCIUM CHLORIDE BRINES

The eutectic temperature of the water solution of calcium chloride is −59.8° F. and the eutectic composition contains 29.8% of the anhydrous material. Thus, calcium brines may be used successfully at any temperature down to approximately −55° F. The specific heat is somewhat less than equivalent common salt brine and the viscosity is greater. For holdover tanks in which the brine is partially frozen to store refrigerating effect, calcium brine is particularly desirable, as the solid salt does not precipitate out until −59.8° F. is attained. Freshly made calcium chloride brine is somewhat alkaline and should be neutralized if it is to be used in contact with galvanized iron. Muriatic acid may be used as a neutralizer, but it requires careful chemical control since an excess will cause vigorous attack upon all metal parts. The simplest method of neutralizing excessive alkalinity is to pass a stream of carbon dioxide gas into the agitated solution until no pink color is produced by adding a drop of phenolphthalein test solution to a teaspoon of the brine.

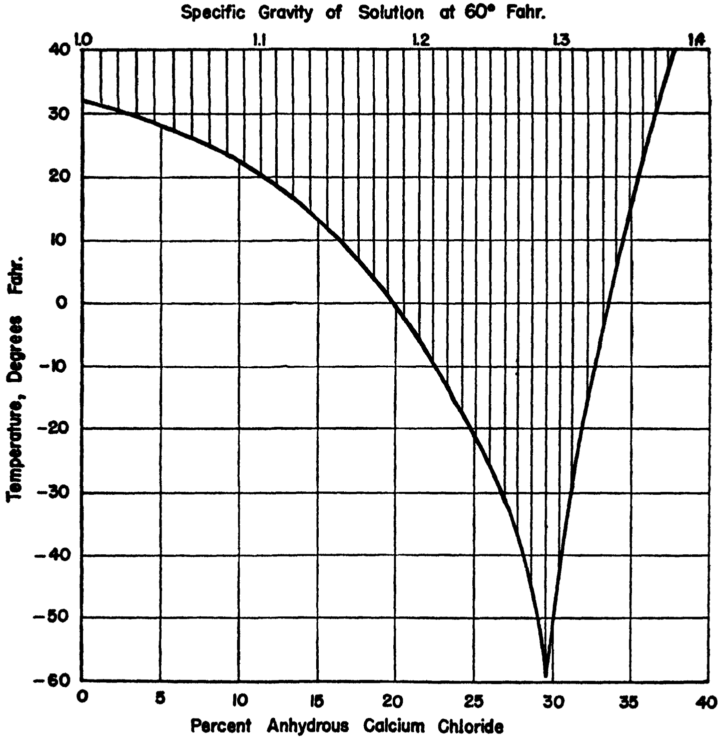

FIG. 7-3. Graph showing freezing point, specific gravity, and percentage composition of calcium chloride brines.

MAGNESIUM CHLORIDE BRINE

The magnesium chloride brines have been employed in areas where the salt is a by-product of chemical works. It has also been used in admixture with calcium chloride which is produced by alkali works using dolomitic limestone as raw material. The eutectic temperature and composition are respectively −26.5° F. and 21.6% for water solutions of pure magnesium chloride. Thus, the lowest temperature for operation of pure magnesium brine is intermediate between the limits of sodium and calcium brines. The characteristics of mixed brines depend upon the relative proportions of the salts in the mixture and this information must be secured from the manufacturers.

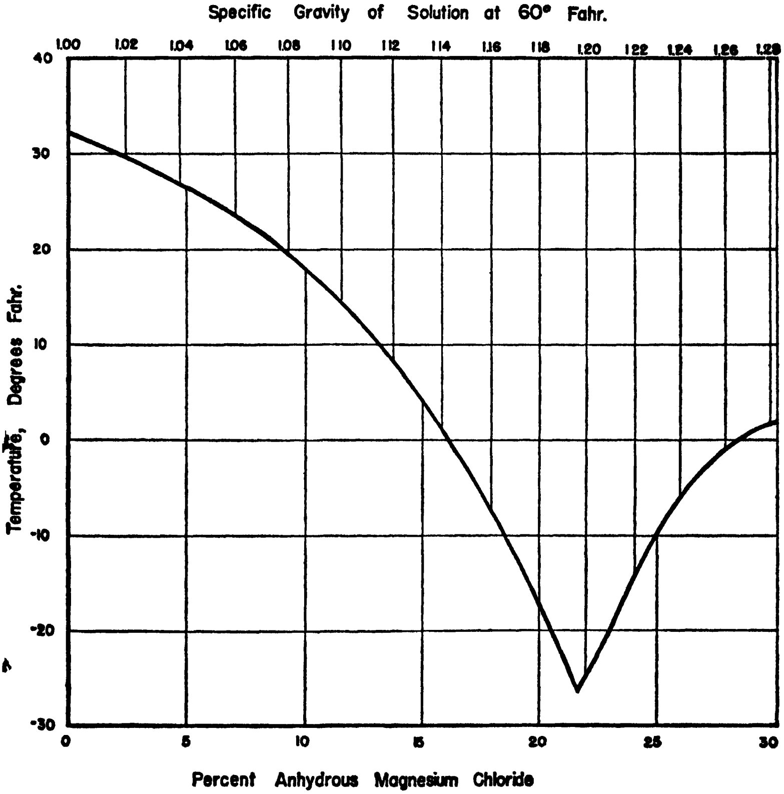

FIG. 7–4. Graph showing freezing point, specific gravity, and percentage composition of magnesium chloride brines.

CORROSION IN BRINE SYSTEMS

Brine systems are usually constructed of iron or steel because of the relatively low cost and convenience of these construction materials. In the presence of water, air and soluble salts, severe rusting and corrosion may occur if steps are not taken to minimize chemical action. At times, some wild claims have been made that certain brines are noncorrosive to metals; however, it may be stated that the chlorides of either sodium, calcium or magnesium will cause corrosion of steel and iron parts in the presence of water and air. The presence of acidic impurities in brine salts greatly accelerates corrosion.

When only iron or steel parts are present in the system, it is desirable to maintain a high degree of alkalinity in the brine. However, zinc alloys and galvanized parts are rapidly attacked by alkali; thus, the brine in an ice tank must be maintained in an approximately neutral condition to prevent attack on the galvanized ice cans.

The terms "acid" and "alkali" are well known and denote very specific materials. Hydrochloric acid is a very corrosive substance which causes severe burns of the skin and rapidly attacks metals, whereas boric acid is so mild that its water solution is used as an eye wash; yet both are true acids. Caustic soda and milk of magnesia are both alkalies, yet one is violently corrosive when swallowed, whereas the other is commonly taken internally. All chemicals possess both acid and alkaline properties. When the acidic property predominates, the substance is said to be an acid and, conversely, when the alkaline character predominates, the term "alkali" is applied. If the acidic character is slightly greater than the alkaline, the material is a weak acid and if an exact balance occurs, the substance is neutral.

The pH Scale. To measure the exact degree of acidity and alkalinity, a special scale has been devised, which is known as the hydrogen ion concentration or the pH scale. On this scale a value of 7.0 indicates that the solution is balanced between acidity and alkalinity; thus, it is neutral. A pH value less than 7.0 indicates that the acidic character predominates, whereas above 7.0 the alkaline property is greatest. The scale is logarithmic in character and a change of one unit indicates that a tenfold change in both acidity and alkalinity has occurred. For instance, at pH 7.0, the acidity and alkalinity are exactly equal, but at pH 8.0, the acidity has decreased tenfold whereas the alkalinity has increased tenfold. The following table of values will show these relations for varying pH values.

TABLE 7-1. ACIDITY AND ALKALINITY OF SOLUTION IN RELATION TO VARYING VALUES OF pH

Value of pH	Relative Acidity of Solution	Relative Alkalinity of Solution
4	1000	0.001
5	100	0.01
6	10	0.1
7	1	1
8	0.1	10
9	0.01	100
10	0.001	1000

Measurement of pH. Exact measurements of pH are made with electrometric apparatus using standard electrodes and a potentiometer. Where a large number of precise determinations must be made, the electrometric pH meter is a necessity, but the colorimetric determination is simple and yields results which are accurate within the range necessary for controlling brine corrosion.

The most dependable colorimetric method for brine control within the range of pH from 6.5 to 8.0 employs the indicator phenolsulfonaphthalein, which is also known as phenol red. A measured quantity of the brine is placed in a test tube, and the proper amount of phenol red indicator solution is added and mixed. The resultant color of the solution is compared with a series of standard tubes of known pH value. This indicator is yellow at pH values below 6.5 and changes through orange to red as the value increases to 8.0. Phenolphthalein is used in a similar manner for determining values between 8.0 and 9.5. The complete apparatus may be secured from laboratory supply houses at a low price and its regular use will pay large dividends in reducing repair costs.

It is desirable to maintain the brine at a pH of approximately 10.0 in systems containing only steel and iron parts, but in the presence of galvanized parts this should be held between 7.0 and 8.0 since zinc is rapidly attacked by acidity or by strong alkalinity. In operation, brines normally increase in acidity because carbon dioxide is absorbed from the air and small quantities of alkali must be added periodically to maintain the desired pH range. Caustic soda is used for treating salt brines and milk of lime for calcium brines. Although the maintenance of proper brine pH is of great importance, this alone is not sufficient to prevent corrosion of the system.

Air in the Brine. Structural metals in contact with water solutions and oxygen or air are invariably subject to corrosion in some degree. From the chemical standpoint, corrosion is most frequently an oxidation process, the oxygen being supplied either by direct exposure to atmosphere or by air dissolved or mechanically held in the brine itself. It is practically impossible to maintain a brine entirely free from air, but there are certain points to remember in connection with keeping the air content as low as possible.

(1) Air is less soluble in a strong brine than in a weak brine; consequently the stronger the brine the less is its tendency to retain air which would cause corrosion.

(2) Any splashing or swirling motion of the brine is likely to introduce air. Such a condition may occur directly over an agitator or by splashing of brine from a return line to a brine tank. In the latter case the obvious remedy is to submerge the end of the return line beneath the brine level in the tank.

(3) Brine pumps have a tendency to suck in air, particularly when the brine flow on the intake side is inadequate to supply the pump with a quantity of brine sufficient to keep it operating at capacity. All glands and stuffing boxes should be kept well packed and turned down tightly to prevent such air leakage.

(4) In a freezing tank the agitators may be operated too rapidly, resulting in lowering of the brine level on the intake side and a consequent sucking in of air through the agitator blades. A dirty screen on the intake side of the agitator will produce the same results.

CORROSION INHIBITORS

It has been found that the addition of small quantities of certain chemicals to brine or circulating water greatly decreases the rate of corrosion of metal parts in the system. The exact method by which these substances act is not well known. In some cases it may be due to the formation of a protective film or coating which prevents direct contact between the brine and the metal surfaces and in other cases the character of the metal surface itself seems to be modified. These substances are known as corrosion inhibitors and have been widely and successfully employed. A brief discussion of application methods has been prepared and published by the American Society of Refrigerating Engineers in A.S.R.E. Circular No. 10. The following paragraphs summarize the findings.

Brief Code of Corrosion Prevention.

Calcium Brine Systems. For calcium chloride brine approximately 100 lbs. of sodium dichromate ($Na_2Cr_2O_7 \cdot 2H_2O$) per 1000 cu. ft. of brine should be added (1.6 grams per liter). There should also be added sufficient sodium hydroxide to convert the dichromate to the neutral chromate. For neutral brines this amount is approximately 27 lbs. per 100 lbs. of dichromate; for ammoniacal brines the amount will be less and in some cases (when the brine shows red with phenolphthalein after the dichromate is added) none will be needed.

The dichromate may be hung in a bag in the brine at a point of rapid circulation or when convenient it is better to dissolve the retarder in a little warm water and pour the solution slowly into the circulating brine. The bag method has the advantage of requiring less labor and insuring better distribution. Approximately one-half of the original amount of dichromate should be added to old brine once a year; analysis of the brine for dichromate would of course be a more advisable way of determining the quantity required, but the amount specified will usually be satisfactory.

In making up a new tank of brine, the brine should be mixed in a separate tank, dichromate (or chromate) added, with sufficient caustic soda to make the brine just alkaline to phenolphthalein and the whole be allowed to stand until the insoluble portion settles. After this is done, the clear brine may be pumped off into the new tank, cooled to the usual temperature and not until then should the cans be placed in the brine. By following this procedure the abnormally high initial corrosion of the galvanizing on the cans can be largely eliminated. Where caustic soda is added to brine solutions in contact with galvanized iron the pH should not exceed 8.5.

Calcium Magnesium Brine Systems. For calcium magnesium chloride brines the same procedure recommended above should be followed except that 200 lbs. of dichromate per 1000 cu. ft. of brine should be used. The method of making up the new brine recommended above is especially advisable in this case.

Sodium Brine System. Sodium dichromate is recommended for sodium brine systems in concentration of 200 lbs. per 1000 cu.

ft. The same procedure of adding alkali and renewing the dichromate annually is necessary.

Phosphate Treatment. For sodium brines in open systems the use of disodium phosphate ($Na_2HPO_4 \cdot 12H_2O$) is suggested as an alternative. Although not as effective as dichromate and requiring frequent renewal, it does not have the disadvantage of irritating and poisoning the skin of workmen. The proper concentration to use is approximately 100 lbs. per 1000 cu. ft. of brine, and this amount should be added once each month. The brine must be kept neutral or only very slightly acid by the addition of muriatic acid if necessary. If phenolphthalein is used to test the brine and a pink color is observed, the acid should be added until the color just disappears. If the British Drug House universal indicator is used the color should be yellow. The retarder must be dissolved in hot water and added slowly to the brine at a point in front of the agitators.

Fresh-water Recirculating Cooling Systems. The use of sodium silicate (water glass) is proper for this type of system. No universal rule can be given for the amount to use. In general, 1.5 gals. of 40° Be silicate per 1000 cu. ft. of make-up water should be used at first. This amount should cause the water to show pink when tested with phenolphthalein after one hour, and if this coloration is not obtained at the end of one week's application, the additions should be increased.

Sodium dichromate is also recommended for recirculating condenser systems, especially where the water comes in contact with corrosive industrial air. The amount required to stop corrosion varies considerably with the water and temperature and may be determined by immersing some clean steel in a continuously aerated sample of the treated water for a week. With the proper additions, only very slight corrosion should be perceptible in that time. The recommended concentration for first trial is 6 lbs. per 1000 cu. ft. of make-up water. Caustic soda (1.75 lbs. per 1000 cu. ft.) should also be added. Dichromate may be injurious to adjoining property when windage losses occur. It therefore has a narrower field of usefulness although it is more effective than the silicate. A large excess above the amount required to stop corrosion should be avoided.

Nonrecirculating Cooling Systems. Because of the large amounts of water used no economical method has yet been devised for the treatment of nonrecirculating fresh or salt water. Corrosion prevention must at present be obtained by use of rust-resisting metals or efficient protective coatings.

The results of the ten months' test of materials suitable for condenser fabrication and coatings indicate that of the ordinary available materials, either hot dipped galvanized steel or wrought iron with not less than 2 oz. of zinc per sq. ft. may be used to advantage in most cases. In all cases, threaded ends of pipes and hot-gas lines should be efficiently protected by the application of a good priming coat containing an inhibitor, covered by a good waterproof material. The surface of the metal should be perfectly dry and clean before painting or coating.

Cleaning Condensers. It is recommended that as far as practicable condensers be kept free from slime and scale, especially during the summer months. The formation of a coating on the pipes raises power costs considerably, and in the average plant, it seems safe to say that the condensers are cleaned far too seldom. Efficient water distribution is equally important in obtaining efficient heat transfer.

MISCELLANEOUS SUGGESTIONS FOR GOOD PLANT PRACTICE

(1) In all systems steps should be taken to prevent, in so far as possible, the agitation of brine in contact with air; all inlets should be sealed. In general, the elimination of dissolved oxygen will largely prevent corrosion difficulties and any efforts in this direction will be well repaid.

(2) It is suggested that weighted test pieces of galvanized and bare iron or steel be hung in the brine system as a convenient method of observing the degree of corrosion or protection resulting from treatment. Indications of pitting should be especially noted.

(3) If brine is not treated it should be maintained slightly alkaline (pH about 8.5). The use of phenolphthalein as an indicator of alkalinity is recommended. A faint pink coloration should be maintained, if necessary, by the addition of a small amount of caustic soda or milk of lime.

(4) Ammonia leaks should be repaired as soon as noticed. Sodium dichromate will usually give good protection to bare or galvanized iron even in strongly ammoniacal brine.

(5) Contact of dissimilar metals should be avoided as far as practicable. The dichromate treatment will in most cases minimize this type of corrosion.

(6) Strict cleanliness observed in and about the tank room in ice plants is advisable.

(7) When paint is to be applied for corrosion protection, it is especially important first to clean the surface thoroughly. Simply brushing off dirt is not sufficient. Removal of scale and dust is absolutely necessary, and heating to remove the small film moisture is advisable before the paint is applied. A good inhibitive priming coat followed by a waterproofing coat properly applied will often give good protection.

(8) A suggested method of protecting exposed threads in galvanized pipe lines in cold storage is by the application of a lacquer, containing flake aluminum or aluminum bronze. All oil and dirt should be removed from the threads before painting.

SECONDARY REFRIGERANTS FOR LOW TEMPERATURES

Calcium chloride brines may be successfully employed at temperatures as low as −55° F., but in general, the water solutions of inorganic salts are not suitable for use at lower temperatures. Some of the hydrocarbons which have very low freezing points are

TABLE 7-2. FREEZING POINT OF WATER SOLUTIONS OF METHANOL (WOOD ALCOHOL) *

Per Cent by Weight	Specific Gravity at 60° F.	Freezing Point, °F.
10	0.982	20.3
15	0.975	13.0
20	0.968	6.3
25	0.961	− 5.5
30	0.953	− 15.7
35	0.946	− 27.3
40	0.937	− 39.0
45	0.928	− 52.0
50	0.919	− 65.0
55	0.908	− 84.0
60	0.898	−103.0
65	0.887	−121.0
70	0.875	−150.0
75	0.863	−184.0
78.26 (Eutectic)	0.860	−218.0

* Calculated from data of R. E. Hall and Miles S. Sherrill, International Critical Tables, Vol. IV, 1928, p. 262, McGraw-Hill Book Co., Inc., New York.

used, but the severe hazard, in case of fire, limits these to small systems. Kerosene varies greatly in composition but, in general, the freezing point of the commercial product is below −100° F. Toluene may be employed down to −160° F.

Water solutions of the alcohols, the glycols or dihydric alcohols and glycerol (glycerin), which is a trihydric alcohol, are most widely used. Methanol, which is also known as wood alcohol, may be used for almost all low-temperature applications since the eutectic temperature of its water solutions is −218° F. Although this alcohol is popularly supposed to be violently poisonous, no danger is to be anticipated unless it is used as a beverage. Employees in establishments which manufacture or use this substance suffer no ill effects if a reasonable amount of care is exercised to prevent prolonged contact with the skin or constant inhalation of the vapor. At low temperatures, the vapor from methanol solutions is negligible. The fire hazard of water solutions of methanol is approximately the same as that of ethyl alcohol solutions having the same freezing temperature.

Ethanol, which is also known as ethyl or grain alcohol, is widely employed as a constituent of anti-freeze solutions. Pure ethanol is

TABLE 7-3. FREEZING POINT OF WATER SOLUTIONS OF ETHANOL (ETHYL ALCOHOL)

Per Cent by Weight	Specific Gravity at 68° F.	Freezing Point, °F.
2.5	0.99363	30.2
4.8	0.98971	28.4
6.8	0.98658	26.6
11.3	0.98006	23.0
13.8	0.97670	21.0
16.4	0.97336	18.5
17.5	0.97194	16.3
18.8	0.97024	15.1
20.3	0.96823	12.9
22.1	0.96578	10.0
24.2	0.96283	6.8
26.7	0.95914	3.2
29.9	0.95400	− 2.0
33.8	0.94715	−10.5
39.0	0.93720	−19.7
46.3	0.92193	−29.0
56.1	0.90008	−41.8
71.9	0.86311	−60.3

subject to very high internal revenue taxes but, after the addition of certain denaturants which impart unpleasant odor and taste, it is sold tax-free for industrial purposes. The added substances have no appreciable effect upon the properties of denatured alcohol as a secondary refrigerant but merely render it unfit for beverage purposes. The eutectic water-ethanol mixture contains 93.5% of the alcohol and freezes at −181° F. In solutions containing more than 45% by weight, it may be ignited at room temperature by sparks or contact with open flames; but at low temperatures the danger from fire is remote even with the more concentrated solutions.

Ethylene glycol is nonvolatile at room temperatures and thus presents less fire hazard than the monohydric alcohols. However, it is very toxic when swallowed and prolonged contact with the skin causes dermatitis. Thus, its use in food refrigeration must be in such equipment that it cannot be accidentally introduced into the product. The eutectic temperature of aqueous ethylene glycol solution is −72° F.

TABLE 7-4. FREEZING POINT OF WATER SOLUTIONS OF ETHYLENE GLYCOL

Per Cent by Weight	Specific Gravity at 60° F.	Freezing Point, °F.
10	1.014	26.1
20	1.026	18.0
30	1.040	7.7
35	1.047	1.2
40	1.054	− 7.8
45	1.061	−16.0
50	1.067	−31.7
55	1.073	−48.0
60	1.079	−50.8

Glycerol or glycerin presents no fire hazard in water solution and is completely nontoxic. The eutectic composition and temperature of its water solution are, respectively, 66.7% glycerol and −51.7° F.

TABLE 7–5. FREEZING POINT OF WATER SOLUTIONS OF GLYCEROL

Per Cent by Weight	Specific Gravity at 68° F.	Freezing Point, °F.
10	1.02395	29.1
20	1.04880	23.4
30	1.07470	14.9
40	1.10135	4.3
50	1.12845	− 7.4
60	1.15605	−28.5
70	1.18355	−36.0
80	1.21090	− 3.5
90	1.23755	29.1
100	1.26362	62.6

SECONDARY REFRIGERANTS FOR DIRECT CONTACT WITH FOODSTUFFS

Several processes have been developed for freezing food by direct contact with chilled liquids. Since some secondary refrigerant will remain upon the foodstuff, it is imperative that it should be edible and either compatible with the flavor of the food or tasteless. Among the liquids which have been used are common salt solutions, glycerol solutions, special sugar solutions and oils. The properties of salt brines and glycerol solutions have been discussed, but very little data have been presented for sugar solutions.

Cane sugar or sucrose is the most readily available of the commercial sugars, but since its eutectic point is only 7.0° F. in water

TABLE 7–6. FREEZING POINT OF WATER SOLUTIONS OF SUCROSE (CANE SUGAR)

Per Cent by Weight	Specific Gravity at 68° F.	Freezing Point, °F.
10	1.038	31.0
20	1.081	29.3
30	1.127	27.1
40	1.176	23.8
50	1.230	18.5
60	1.286	9.2
62.4 (Eutectic)	1.301	7.0

solution and the eutectic composition is 62.4%, its utility for this purpose is limited. Furthermore, the viscosity of the solution at low temperature is very great.

Dextrose or corn sugar is quite unsuitable, as its eutectic temperature is 22.5° F. and the eutectic composition is 31.7% anhydrous dextrose and 68.3% water.

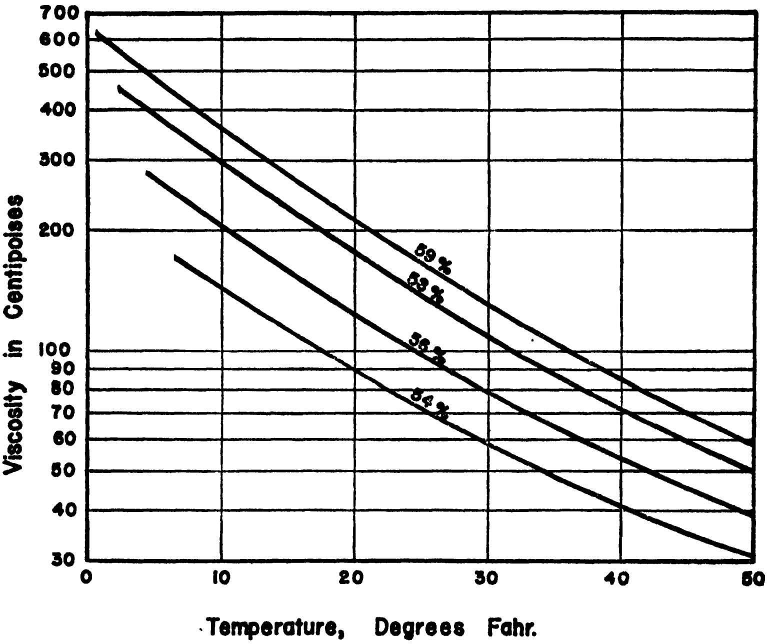

FIG. 7-5. Viscosity of aqueous solutions of invert sugar.

Invert sugar solutions have been used with marked success for freezing fruits. Cane sugar solutions are treated with an inverting enzyme or acid and the resulting product, consisting of equal parts of dextrose and levulose, is utilized as a secondary refrigerant. The articles to be frozen are immersed or sprayed with the solution, which has been chilled to a temperature below the freezing point of the food. After the desired temperature is attained, the food is drained to remove excess solution and the frozen product is packaged and placed in freezer storage. The freezing points and viscosities of invert sugar solutions have been determined by the authors and may be used at temperatures as low as 5° F. Below this temperature, ice is likely to form upon the refrigerating surfaces and greatly impede the flow of heat.

TABLE 7–7. FREEZING POINT OF AQUEOUS SOLUTIONS OF INVERT SUGAR

Per Cent by Weight	Specific Gravity at 68° F.	Freezing point, °F.
10	1.037	29.9
20	1.080	27.1
30	1.126	23.5
40	1.171	17.7
50	1.226	10.7
55	1.253	5.6
58	1.270	2.0

More concentrated solutions precipitate solid hydrated dextrose crystals at low temperatures.

ELECTROLYTIC CORROSION

In spite of the exercise of vigilance in maintaining the proper pH, excluding oxygen and using inhibitors in brine systems, corrosion cannot be entirely eliminated. The electrolytic theory has focused attention on the cathodic method of protection which has been exhaustively investigated by Warner and McCrocklin.* Much of the information given herewith is taken from this bulletin by courtesy of the authors.

In order to explain the action of the cathodic method of corrosion control, a short review of the electrolytic theory of corrosion is necessary. Originally it was thought that corrosion resulted from the direct combination of oxygen with metal. However, this theory did not account for corrosion under many conditions so that when more information was obtained about the action of electrons and ions in solutions, it was realized that the original theory was quite inadequate.

According to the electrolytic theory, corrosion occurs when the metal or metals involved are in direct contact with an electrolyte.

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* "Cathodic Protection of Metals in Ice Plants," *Eng. Res. Bulletin No. 36*, The Univ. of Texas.

This electrolyte may be in the form of an acid or alkali solution, moist earth, plain water, or simply moisture in the air. Resulting from this contact, a difference of electric potential, or voltage, is set up between any two metals that may be present, or even between two spots on the same piece of metal. Several things may give rise to such difference of potential. One of the most common is unlike chemical composition or a difference in molecular structure. It also may be due to internal molecular strains or to differences in temperature between two parts of the same piece of metal. On account of this condition, a small electric battery is formed and since the body of the metal itself short-circuits this battery voltage, a minute electric current flows continuously. This is shown diagrammatically in Figure 7–6. Figure 7–7 shows the same situation when two different metals are involved.

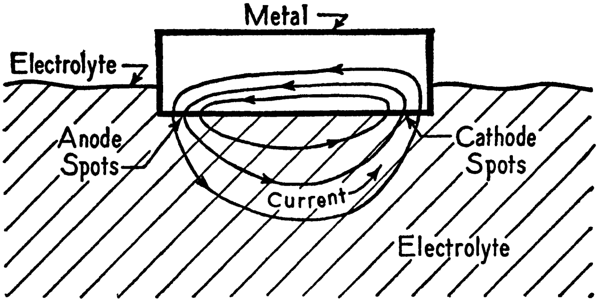


FIG. 7–6.

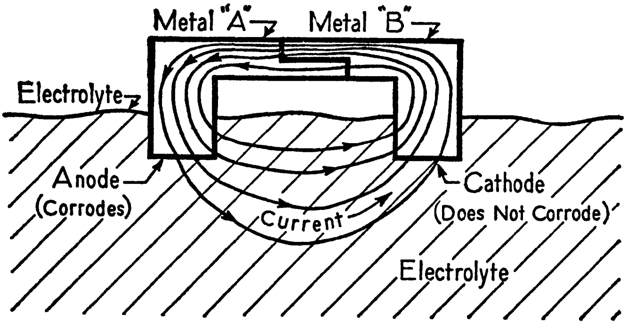


FIG. 7–7.

Electric current is believed to consist of the flow of electrons at a certain rate through a circuit and if these electrons move through an electrolyte from one metal to another or from one spot on a piece of metal to another spot, some of the metal itself is converted into the ionized form.

An ion is a molecule that has lost one or more electrons and is therefore positively charged. These minute particles in the form of ions are permanently detached from the original metal and pass into the electrolyte. In most cases, they finally combine with oxygen and other elements to form oxides, hydroxides, salts or complex compounds. In the case of iron or steel, the oxide formed is known as common rust.

This action occurs only at places where the electric current *leaves* the metal to enter the electrolyte because it is here only that the metal ions mentioned above are produced. The metal at this point in the electric circuit is known as the "anode."

At the opposite side of the circuit where the electric current leaves the electrolyte to *enter* the metal, a somewhat reversed process takes place. If there are metal ions of the right type in contact with the metal itself, they are changed to the metallic form and are deposited or plated upon the metal. A familiar example of this action is the well-known commercial process whereby metals such as silver, copper, nickel and others may be removed from a solution of the salts of these same metals and plated upon another metal solely by the action of the electric current. The metal or spot where current thus leaves the electrolyte is known as the "cathode."

Chemically, this process is expressed by the equation:

$$\mathrm{Me}^{\circ} \rightarrow \mathrm{Me}^{n(+)} + \mathrm{n}(-),$$

where Me° represents any metal in its original or metallic state, $\mathrm{Me}^{n(+)}$ represents an atom of the same metal in the ionized state wherein it has lost n electrons designated by $(-)$. The term $\mathrm{Me}^{n(+)}$ represents an atom of the metal that is detached from the original surface ultimately to combine with oxygen or other elements and give evidence of corrosion. The reverse or plating action is represented by the equation:

$$\mathrm{Me}^{n(+)} + \mathrm{n}(-) \rightarrow \mathrm{Me}^{\circ}.$$

Finally, corrosion will take place at all points or spots that are "anodic" but will not occur at places which are "cathodic." This fact gives rise to the name of this electrical or electrolytic method of corrosion control.

Factors Affecting Corrosion. According to the electrolytic theory, corrosion is due to the electrolytic transfer of metal accompanying the flow of electric current through a solution which is in contact with the metal. In order for current to flow, it is necessary that there be a difference of potential between the points of flow.

Metal Potentials. Every metal exhibits a natural potential with respect to an electrolyte, which is any solution capable of carrying an electric current. Moist earth, even, may serve as an electrolyte. The value of this potential depends upon the temperature of the electrolyte, temperature of the metal, concentration of the electrolyte, kind of metal, kind of electrolyte and the molecular condition of the metal, i.e., whether annealed or under strain.

In the ice plant, iron or steel ice cans and ammonia coils are submerged in a solution of salt contained in the large steel tank. The salt solution forms a convenient electrolyte for any current that may flow in response to such differences of potential or voltages set up between the parts of the system. The iron or steel at all points has a natural potential with respect to the brine and if any condition causes this potential to be higher at one spot than at another, an electric battery, or battery couple, is formed, and, if a return path exists, current will flow between those points. The return path is provided by the body of metal, which in effect short-circuits the battery. This condition also is illustrated in Figures 7-6 and 7-7.

Effect of Temperature. Difference in temperature causes a difference of potential If the bottom of an ice can is colder than the top, current will flow in the brine from top to bottom and in the metallic wall of the can from bottom to top, thus completing the electric circuit. Due to the circulation of the brine a difference of temperature will exist between various sections of the ammonia coil system. Current will flow between such points. The velocity of the circulating brine also may affect the amount of potential difference between parts of the system, although this may simply be related to the temperature gradient.

Metal Conditions in Ice Plants. If unrelieved stresses exist in any parts of the ammonia coil system, such as at welded joints, battery couples are formed. Welds are particularly subject to corrosion if the composition of the welding rod was not the same as that of the metals welded together. A condition frequently found in ice plants which greatly favors corrosion is the use of metals which are naturally quite unlike in contact with each other. Cast-iron fittings on steel pipe are an example. Brass in contact with iron or steel is always conducive to corrosion and brass air tubes frequently are attached to the galvanized sides of ice cans. Bronze impeller wheels often are placed on iron shafts of circulating pumps. If any two unlike metals are in contact with each other under the brine, a battery couple is formed and current will flow.

Riveted joints and seams in ice cans frequently are wiped with solder, an alloy of lead and tin. The resulting potential difference is short-circuited by some metallic part so that current flows constantly with accompanying corrosion.

Brine Solution pH Value. A very important factor in the rapidity of corrosion is the degree of acidity or alkalinity of the brine solution. This is indicated by the concentration of the hydrogen ion in the solution as expressed by the symbol pH. A pH value of 7.0 denotes a neutral solution. A value above this indicates that the brine is alkaline, while one below 7.0 means the brine is acid. Values of pH from 7.0 to 8.2 result in minimum differences of potential and minimum changes in conductivity of the electrolyte with consequently the least tendency to corrosion.

Theory of Cathodic Protection. According to the electrolytic theory of corrosion, natural potentials which are set up between metals and parts of metallic equipment when in contact with an electrolyte cause minute electric currents to flow. Wherever these currents flow away from a spot on a piece of metal and enter the electrolyte, disintegration or corrosion takes place at the spot and the extent or rapidity of such corrosion is proportional to the density of this current.

Knowledge of this electrolytic process at once suggests the possibility of devising an electrical remedy. If the minute batteries within the system could be overcome and the electrical current stopped or forced to flow only in the correct direction, corrosion would be prevented. It is relatively easy to do this and the method of *cathodic protection* depends upon the control of this internal current. It is necessary only to provide an external source of electrical energy and the flow of current within the system is thereby brought almost entirely under the regulation of the operator.

It should be noted that it is unnecessary to reverse the natural potentials between metal and electrolyte or between metals in order to accomplish protection. The natural current flow may be reversed but the natural potentials are lowered only somewhat in proportion to the current sent into the system. This action is readily understood by reference to the ordinary storage battery. Under discharge, current flows *away* from the positive terminal into the external circuit. When the battery is charged, current is sent *into* the battery at the positive terminal. The current is reversed but the polarity remains unchanged.

Cathodic protection, then, depends upon forcing current to *enter* all metals and surfaces it is desired to protect—that is, forcing them to become electrolytic cathodes. The amount of voltage by which the natural potentials are lowered as a result of this current flow is known as the "protecting voltage." It depends upon a number of conditions as well as upon the amount of current flowing and will be discussed later.

It is necessary to complete the electrical circuit and in order to provide a point where the current will harmlessly enter the electrolyte, an artificial anode must be provided. This may consist of any piece of metal submerged in the electrolyte—something that is inexpensive, replaceable and of suitable composition. All of the corrosion of the system then will be centered at this replaceable anode. This is illustrated in Figure 7–8, which shows current leaving the anode, flowing through the brine and entering the ammonia pipes and cans in the ice plant.

Surface Films. The electrolyte in the ice plant is a liquid, salt solution; therefore, the positively charged metal ions detached from the anode are free to travel over to the cathode under the influence of the current. Here, they become neutralized and are deposited in the form of a semi-liquid film on the surface being protected. Some metals, if used as anodes in electrolytes, will form objectionable films. The safest rule is to use a metal that is more active than the one to be protected. Chemically, this film is of the nature of a complex hydroxide of the metal which is used as the anode and its presence on the surface of the cathode is the best evidence that the system of protection is functioning properly.

Even if the protecting current is stopped, this film by itself will furnish protection for a short time—probably for several days. After that the film becomes dissolved by the brine and conditions favoring corrosion return.

In the light of the foregoing theory, the action of chemical corrosion inhibitors is further explained. They form a thin chemical film on the surface of metals under the electrolyte and this film reduces the natural potentials exhibited by the metals to the brine and between the metals themselves. In turn, the internal current is lowered and corrosion is reduced correspondingly.

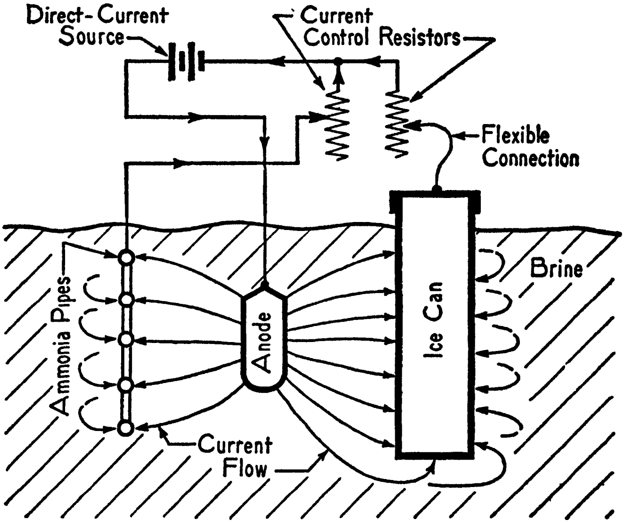


FIG. 7-8.

This electrolytic protecting film is deposited over every minute spot on the surface of the metal being protected. The electrical resistance of the metal to brine is so low that the current distribution is essentially uniform. This means that the protecting film will tend to be formed with practically uniform distribution regardless of the concentration of flow of the brine.

For various practical reasons, complete elimination of corrosion frequently cannot be secured by cathodic protection, although the amount of destruction can readily be reduced to only a small fraction of what would otherwise occur.

Plant Tests. In order to apply cathodic protection, it is necessary to investigate and determine carefully the voltage conditions existing throughout the plant. The rapidity and seriousness of corrosion can be judged by inspection and by examination of plant records as to the frequency of replacements and repairs in the past. Determinations of pH values can be made by the usual comparative tests which are familiar to all plant operators. Temperature measurements and gradients can readily be made, although usually they are not particularly significant. Most important are the differences of potential or voltages that exist between the various parts such as coils, cans and tank. The presence of such voltages is proof that corrosion probably is taking place and their magnitude is a measure of its rapidity.

Voltages existing in an ice tank are relatively small compared to ordinary commercial values, being on the order of thousandths of volts or millivolts. An ordinary millivoltmeter cannot be used directly to measure these voltages because the batteries that give rise to them have capacities too low to operate commercial meters. Therefore, a method must be used which takes no current from these minute cells. Such a scheme is known as a *null method.*

One of the most accurate instruments suitable for such measurements is the electron potentiometer. One of these built in the electrical engineering laboratory was used for comparative measurements. However, this is a device much too delicate for ordinary field work and a more simple type of potentiometer is generally quite satisfactory. It can be purchased as a unit or set up with easily obtained parts. In effect, it consists of an ordinary 1.5-volt storage battery, a slide-wire resistor, a portable galvanometer, a variable-range, low-reading voltmeter, a key and reversing switch. This is shown in Figure 7–9.

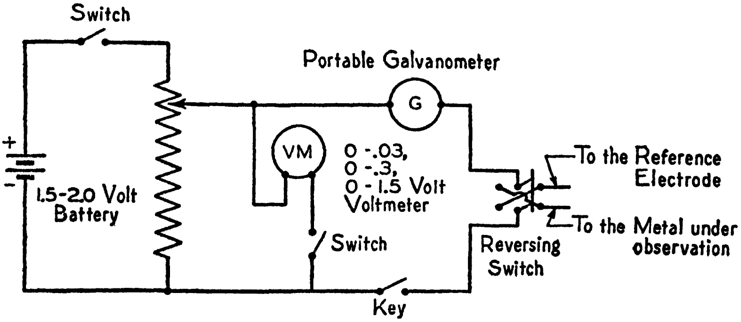


FIG. 7–9.

The slide-wire resistor is connected across the 1.5-volt battery with a switch for convenience in disconnecting when not in use.

Voltages from points in the ice plant system are then balanced against a part of the voltage drop across the slide-wire resistor. When an exact balance is reached, the galvanometer will give no deflection when the key is depressed and the voltage across that portion of the resistor used is then read with an ordinary millivoltmeter. Voltages usually found range from 200 millivolts positive to around 500 millivolts negative. A reversing switch is used to avoid having to take time to change connections in case the meter happens to be reversed and does not read up scale.

Apparatus of this kind is rugged and readily portable. With it a complete voltage survey of a plant can be made within a few hours. It is best to measure all voltages with reference to some convenient point which may be ammonia coils, outside tank or an external water main.

Basic Precautions. Corrosion occurs almost everywhere in the ice plant so that every possible care should be taken in controlling it. All conditions that inherently favor corrosion should carefully be avoided. The use of different metals in contact with each other should not be permitted. Brass air pipes on steel cans should not be used. Brass fittings on steel or iron pipe promote corrosion. Even the use of cast-iron fittings with wrought iron or steel pipe is a bad practice. Welded joints are much better but the welding rod must be very similar to the pipe in composition or electrolytic action will take place at the weld and cause it to fail within a few years.

Ice cans themselves often are inadvertently constructed so as to favor corrosion. The seams are riveted and the joint is covered with solder, a lead and tin alloy, thus placing three metals in contact, which is inherently bad. The standing joint on the bottom traps air under the can every time it is lowered into the brine. If a joint of this type is necessary, some provision should be made for allowing the air to escape.

One of the most vulnerable places on the can is at the brine line. Frequently cans fail first at this point. Corrosion here is particularly bad because of the temperature difference between the moist can just above the brine line and the submerged surface just beneath the brine and it is difficult to overcome this unfavorable condition. The use of an asphaltic paint of some nature around the top of the can might be of some benefit.

Galvanizing on a can seems to be of little value against corrosion. It may serve to keep the water and ice inside the can clear, but on the outside it disappears so quickly that it would seem to be quite worthless. The metallic film of zinc hydroxide formed on the surface of the cans under cathodic protection is permanent as long as the method is correctly applied and is far more effective than any galvanizing.

Without doubt there is considerable merit in many of the various chemical treatments applicable to the brine. It was shown above that the amount of current necessary for cathodic protection would be reduced if the brine were chemically treated. Therefore, it would seem logical to consider using chemical treatment in addition to electrical protection.

There is always a possibility that stray earth currents from outside sources of direct current may pass through the tank, since it is usually in more or less direct contact with the earth. Wherever current happens to leave the tank for the earth, corrosion will be particularly bad. To prevent this, the tank should be thoroughly grounded to a water main or else to an artificial ground made of large junk castings buried in the earth and kept moist. In some cases it might be advisable also to ground the evaporator coils.

Protecting Voltage Necessary. A protecting voltage of between 200 and 400 millivolts negative is usually enough to counterbalance all the variations in voltage from time to time due to changes of brine temperature and specific gravity. This voltage also is usually sufficient to hold all the metals it is desired to protect at a potential low enough to insure that the current will flow only toward them under the surface of the brine. Voltage variations may be determined by means of the potentiometer circuit shown in Figure 7–9 where the tank itself is used as a reference level. Such measurements will not give the voltage of the cans or coils to the brine but will indicate the order of the protecting voltage necessary.

Potential Measurements. It is frequently helpful in applying cathodic protection to have some idea of the potential of the ice cans and ammonia pipes with respect to the brine itself. This can readily be measured by means of the circuit in Figure 7–9 using a reference electrode immersed directly in the brine.

A small piece of sheet platinum or platinum wire will serve for such an electrode. The junction between the platinum and a copper lead to the measuring apparatus must be kept perfectly dry or an additional unwanted voltage will be introduced and spoil the results. To do this, it is best to seal the platinum into the end of a glass tube. The junction between the copper and platinum should be welded and also placed within the glass tube which should be filled with paraffin to keep out moisture. The outside of the glass tube should be kept perfectly dry.

A piece of carbon from an ordinary No. 6 dry battery also will serve reasonably well as a reference electrode. In order to keep the junction between carbon and copper lead dry, it should all be coated with paraffin except at the lower end. Before using it each time, the carbon should be washed with dilute hydrochloric acid.

There are certain inaccuracies inherent in the results obtained with both of the electrodes described above due to the difference in temperature between the brine and the metal at the point contact is made. However, this error is only a very small per cent of the total potential difference and therefore for this type of work may safely be neglected.

Application of the Protecting System. The essential parts of the cathodic protecting system consist simply of a source of low-voltage, direct-current—usually a dry-type rectifier—anode of suitable metal such as zinc or aluminum, resistors, meters and suitable connectors to the cans and pipes to be protected. A wiring diagram of a typical system is shown in Figure 7–8.

If both cans and ammonia pipes are to be protected, it may be necessary to place separate resistors in series with the ammonia pipes or coils, also as shown in Figure 7–8, in order to control the current distribution between cans and pipes because, in general, less current is required to protect them than is necessary for the cans.

Once the average temperature of the brine is known, the current density in milliamperes per square foot of can surface may be determined from the curves of Figure 7–10 or for the ammonia pipes from Figure 7–11. It can be seen that usually this is around 4 or 5 milliamperes per sq. ft. Knowing the number of cans and amount of ammonia pipe surface in the plant, the total current needed may quickly be calculated. After the system has been in operation for a short time, the characteristic gray, protecting film can be expected to appear on the surface of the parts connected. As soon as this film becomes well formed, the current density may be reduced, in the interests of economy, to a value just sufficient to maintain it at all points and at all times.

The ammeter shown in Figure 7–9 indicates the amount of current going into the system. It should be of a recording type. In

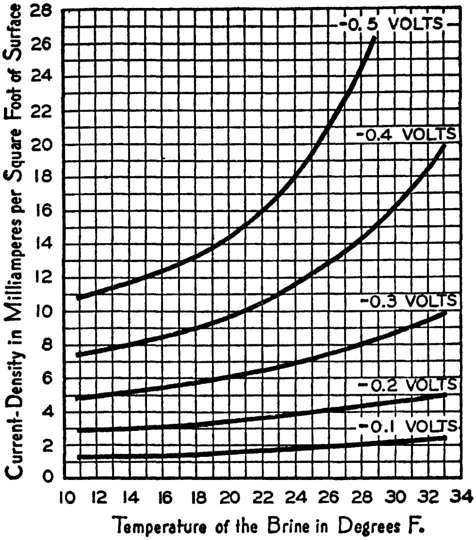


FIG. 7–10. Variation of current density with brine temperature necessary to maintain protecting voltages at the surface of ice cans.

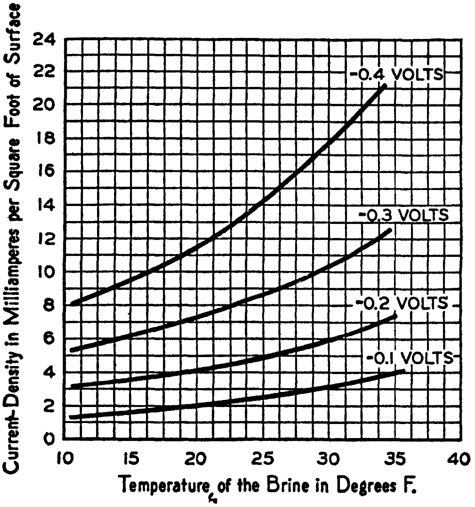


FIG. 7–11. Variation of current density with brine temperature necessary to maintain protecting voltage at the surfaces of brine tank and ammonia pipes.

order to determine the amount of electrical energy used, an ordinary watt-hour meter should be installed in the line from the alternating-current source.

Since plant conditions vary so widely, no single set of operating instructions can be drawn up to fit all cases. However, once the system is placed in operation, the test of its effectiveness is in the formulation of the protecting surface film and the absence of corrosion. These conditions can readily be observed by the operators.

SUMMARY OF RECOMMENDATIONS ON ICE-PLANT CORROSION CONTROL BY CATHODIC PRODUCTION

Cathodic Protection Procedure.

(1) Determine brine-tank potentials.
(2) Install cathodic protecting system.
(3) Maintain current at correct value.
(4) Inspect cans and piping for protecting film and absence of corrosion.
(5) Start system of records of can replacements and repairs due to corrosion.

Critical Points in Ice Plant Brine Tanks and Precautions.

(1) Brine line on ice cans.
(2) Seams in ice cans, rivets.
(3) Bottom of ice can—account of entrapped air.
(4) Joints and fittings of ammonia piping.
(5) Brine agitator propellors.

Precautionary Aids in Reducing Corrosion.

(1) Use chemical treatment also.
(2) Keep a variety of metals out of tank.
(3) Buy cans with welded seams and openings into space beneath bottom.
(4) Avoid brass air pipes welded to side of can.
(5) Avoid brass in contact with steel anywhere.

SUPPLEMENTARY TABLES AND CHARTS

The following tables and charts are reprinted by permission of the Calcium Chloride Association.

TABLE 7-8. DENSITIES, FREEZING POINTS AND CONCENTRATIONS OF CALCIUM CHLORIDE BRINES

*SPECIFIC GRAVITY 60/60°F.	°BAUMÉ AT 60°F. (AM. STD.)	SALIMETER READING AT 60°F	WEIGHT OF BRINE AT 60°F.		% $CaCl_2$ ACTUAL	FREEZING POINT °F.	LBS. 73-75% SOLID $CaCl_2$		LBS. 77-80% FLAKE $CaCl_2$		**LBS. PER GALLON OF WATER AT 60°F.		***FINAL VOLUME IN GALS. AT 60°F.
			LBS. PER GALLON	LBS. PER CU. FT.			LBS. PER GALLON OF BRINE AT 60°F	LBS. PER CU. FT. OF BRINE AT 60°F	LBS. PER GALLON OF BRINE AT 60°F.	LBS. PER CU. FT. OF BRINE AT 60°F.	SOLID 73-75 $CaCl_2$	FLAKE 77-80 $CaCl_2$	
1.000	0.0	4.0	8.34	62.37	0	+32.0	—	—	—	—	—	—	1.000
1.009	1.3	5.2	8.41	62.93	**1.0**	+31.1	0.11	0.86	0.10	0.81	0.11	0.10	1.004
1.010	1.4	5.6	8.42	62.99	1.2	+31.0	0.14	1.03	0.13	0.97	0.14	0.13	1.006
1.018	2.5	10.0	8.49	63.49	**2.0**	+30.4	0.23	1.73	0.22	1.63	0.23	0.22	1.008
1.020	2.8	11.2	8.50	63.61	2.3	+30.2	0.27	1.99	0.25	1.88	0.27	0.25	1.011
1.026	3.7	14.8	8.55	63.99	**3.0**	+29.5	0.35	2.61	0.33	2.46	0.36	0.33	1.014
1.030	4.2	16.8	8.59	64.24	3.5	+29.1	0.41	3.06	0.39	2.88	0.42	0.40	1.017
1.034	4.8	19.2	8.62	64.49	**4.0**	+28.6	0.47	3.51	0.44	3.31	0.48	0.45	1.020
1.040	5.6	22.4	8.67	64.86	4.6	+28.0	0.54	4.06	0.51	3.83	0.55	0.52	1.022
1.043	6.0	24.0	8.70	65.05	**5.0**	+27.7	0.59	4.43	0.56	4.17	0.61	0.57	1.024
1.050	6.9	27.6	8.75	65.48	5.9	+27.0	0.70	5.26	0.66	4.96	0.72	0.68	1.030
1.052	7.1	28.4	8.77	65.61	**6.0**	+26.8	0.72	5.36	0.68	5.05	0.75	0.70	1.031
1.060	8.2	32.8	8.84	66.11	**7.0**	+25.9	0.84	6.30	0.79	5.94	0.88	0.82	1.036
1.069	9.4	37.6	8.91	66.67	**8.0**	+24.6	0.97	7.26	0.91	6.84	1.02	0.95	1.043
1.070	9.5	38.0	8.92	66.73	8.1	+24.6	0.98	7.35	0.92	6.93	1.03	0.96	1.043
1.078	10.5	42.0	8.99	67.23	**9.0**	+23.5	1.10	8.23	1.04	7.76	1.16	1.09	1.049
1.080	10.7	42.8	9.00	67.36	9.2	+23.2	1.13	8.43	1.06	7.94	1.20	1.11	1.050
1.087	11.6	46.4	9.06	67.79	**10.0**	+22.3	1.23	9.22	1.16	8.69	1.31	1.22	1.055
1.090	12.0	48.0	9.09	67.98	10.3	+21.9	1.27	9.53	1.20	8.89	1.36	1.28	1.058
1.096	12.7	50.8	9.14	68.35	**11.0**	+20.8	1.37	10.23	1.29	9.64	1.47	1.37	1.062
1.100	13.2	52.8	9.17	68.60	11.4	+20.3	1.42	10.64	1.34	10.03	1.53	1.43	1.065
1.105	13.8	55.2	9.21	68.92	**12.0**	+19.3	1.50	11.25	1.41	10.60	1.62	1.51	1.069
1.110	14.3	57.2	9.25	69.23	12.4	+18.7	1.56	11.68	1.47	11.01	1.69	1.57	1.071
1.115	15.0	60.0	9.30	69.54	13.0	+17.6	1.64	12.30	1.55	11.59	1.79	1.67	1.076
1.120	15.5	62.0	9.34	69.85	13.5	+16.5	1.72	12.83	1.62	12.09	1.88	1.75	1.080
1.125	16.1	64.4	9.38	70.16	**14.0**	+15.5	1.79	13.36	1.69	12.59	1.97	1.83	1.084
1.130	16.7	66.8	9.42	70.47	14.5	+14.5	1.86	13.90	1.75	13.10	2.05	1.90	1.087
1.135	17.2	68.8	9.46	70.79	**15.0**	+13.5	1.93	14.45	1.82	13.62	2.14	1.99	1.092
1.140	17.8	71.2	9.50	71.10	15.6	+12.2	2.02	15.09	1.90	14.22	2.25	2.08	1.096
1.145	18.4	73.6	9.55	71.41	**16.0**	+11.2	2.08	15.54	1.96	14.64	2.32	2.16	1.099
1.150	18.9	75.6	9.59	71.72	16.6	+ 9.7	2.17	16.20	2.04	15.27	2.44	2.25	1.104
1.155	19.4	77.6	9.63	72.03	**17.0**	+ 8.6	2.23	16.66	2.10	15.70	2.51	2.33	1.109
1.160	20.0	80.0	9.67	72.35	17.6	+ 7.0	2.32	17.32	2.19	16.32	2.63	2.44	1.113
1.165	20.5	82.0	9.71	72.66	**18.0**	+ 5.9	2.38	17.79	2.24	16.76	2.71	2.50	1.118
1.170	21.1	84.4	9.75	72.97	18.6	+ 4.1	2.47	18.47	2.33	17.40	2.83	2.62	1.122
1.175	21.6	86.4	9.80	73.28	**19.0**	+ 2.8	2.53	18.94	2.38	17.85	2.90	2.68	1.127
1.180	22.1	88.4	9.84	73.59	19.5	+ 1.2	2.61	19.52	2.46	18.39	3.01	2.78	1.131
1.186	22.7	90.8	9.89	73.97	**20.0**	− 0.4	2.69	20.13	2.53	18.97	3.12	2.87	1.137
1.190	23.2	92.8	9.92	74.22	20.6	− 2.0	2.78	20.80	2.62	19.60	3.25	2.99	1.142
1.195	23.7	94.8	9.96	74.53	**21.0**	− 3.9	2.85	21.29	2.69	20.06	3.34	3.08	1.147

1.200	24.2	96.8	10.00	74.84	21.5	−5.8	2.93	21.89	2.76	20.63	3.45	3.18	1.152
1.206	24.8	99.2	10.05	75.21	**22.0**	−7.8	3.01	22.51	2.84	21.21	3.56	3.28	1.157
1.210	25.2	100.8	10.09	75.46	22.4	−9.4	3.08	23.00	2.90	21.67	3.67	3.36	1.160
1.218	25.9	103.6	10.15	75.96	**23.0**	−11.9	3.18	23.77	3.00	22.40	3.80	3.50	1.168
1.220	26.2	104.8	10.17	76.09	23.3	−13.2	3.22	24.12	3.03	22.73	3.86	3.54	1.170
1.228	26.9	107.6	10.24	76.59	**24.0**	−16.2	3.34	25.01	3.15	23.57	4.04	3.71	1.178
1.230	27.1	108.4	10.25	76.71	24.2	−17.1	3.37	25.26	3.18	23.80	4.08	3.75	1.180
1.239	28.0	112.0	10.33	77.27	**25.0**	−21.0	3.51	26.28	3.31	24.76	4.29	3.93	1.189
1.240	28.1	112.4	10.34	77.33	25.1	−21.5	3.53	26.41	3.33	24.89	4.32	3.96	1.190
1.250	29.0	116.0	10.42	77.96	**26.0**	−25.8	3.69	27.58	3.48	25.99	4.57	4.18	1.202
1.260	29.9	119.6	10.50	78.58	**27.0**	−31.2	3.86	28.87	3.64	27.20	4.84	4.42	1.215
1.270	30.8	—	10.59	79.21	27.8	−37.1	4.01	29.96	3.79	28.23	5.08	4.65	1.227
1.272	31.0	—	10.60	79.33	**28.0**	−37.8	4.04	30.22	3.81	28.48	5.13	4.68	1.228
1.280	31.7	—	10.67	79.83	28.7	−44.3	4.17	31.17	3.93	29.37	5.35	4.86	1.237
1.283	32.0	—	10.70	80.02	**29.0**	−49.4	4.22	31.57	3.98	29.75	5.43	4.94	1.241
1.290	32.6	—	10.75	80.45	29.6	−59.8	4.33	32.40	4.08	30.53	5.62	5.10	1.250
1.295	33.0	—	10.80	80.76	**30.0**	−50.8	4.41	32.96	4.16	31.06	5.76	5.23	1.256
1.300	33.5	—	10.84	81.08	30.5	−41.8	4.50	33.65	4.24	31.71	5.92	5.36	1.264
1.306	34.0	—	10.89	81.45	**31.0**	−33.2	4.59	34.35	4.33	32.37	6.08	5.51	1.272
1.310	34.3	—	10.92	81.70	31.3	−29.2	4.65	34.79	4.38	32.78	6.18	5.58	1.278
1.317	34.9	—	10.98	82.14	**32.0**	−19.5	4.78	35.76	4.50	33.70	6.43	5.79	1.288
1.320	35.1	—	11.01	82.32	32.2	−17.0	4.82	36.06	4.54	33.98	6.50	5.86	1.293
1.328	35.8	—	11.07	82.82	**33.0**	−6.9	4.97	37.18	4.68	35.03	6.79	6.11	1.305
1.330	36.0	—	11.09	82.95	33.2	−4.7	5.01	37.47	4.72	35.31	6.87	6.18	1.309
1.340	36.8	—	11.17	83.57	**34.0**	+4.3	5.17	38.66	4.87	36.43	7.19	6.45	1.324
1.350	37.6	—	11.26	84.19	34.9	+14.3	5.35	39.98	5.04	37.67	7.56	6.76	1.341
1.351	37.7	—	11.26	84.26	**35.0**	+14.4	5.36	40.12	5.05	37.81	7.57	6.78	1.343
1.360	38.4	—	11.34	84.82	35.8	+21.7	5.52	41.31	5.20	38.93	7.91	7.07	1.359
1.363	38.6	—	11.36	85.01	**36.0**	+24.1	5.56	41.64	5.24	39.24	8.00	7.14	1.363
1.370	39.0	—	11.42	85.44	36.4	+30.0	5.66	42.31	5.33	39.87	8.19	7.30	1.375
1.374	39.5	—	11.46	85.69	**37.0**	+33.4	5.77	43.14	5.44	40.65	8.47	7.54	1.383
1.380	39.9	—	11.51	86.07	37.4	+37.0	5.86	43.80	5.52	41.27	8.66	7.69	1.393
1.386	40.4	—	11.56	86.44	**38.0**	+42.1	5.98	44.69	5.63	42.11	8.95	7.93	1.407
1.390	40.7	—	11.59	86.69	38.3	+44.4	6.04	45.17	5.69	42.56	9.08	8.05	1.414
1.398	41.3	—	11.66	87.19	**39.0**	+49.6	6.19	46.26	5.83	43.59	9.45	8.35	1.431
1.400	41.4	—	11.67	87.31	39.2	+50.9	6.22	46.57	5.86	43.88	9.52	8.41	1.435
1.410	42.2	—	11.76	87.94	**40.0**	+55.9	6.40	47.86	6.03	45.10	9.97	8.79	1.457
					40.9	+61.0							
					41.0	+61.5							
					41.7	+64.8							
					42.0	+65.8							
					42.5	+68.0							
					43.0	+69.8							
					43.3	+70.9							
					44.0	+73.0							
					44.2	+73.6							
					45.0	+75.6							

* Hydrometers giving specific gravities and freezing points of calcium chloride brines can be obtained from any calcium chloride producer.

** Pounds of solid or flake calcium chloride per cubic foot if water at 60° F. may be obtained by multiplying the quantity in pounds per gallon by 7.481.

*** Final volume in gallons at 60° F. when quantity of flake calcium chloride shown in previous column is added to one gallon of water.

NOTE

At concentrations above 40.8% calcium chloride solutions contain suspended crystals at 60° F., and therefore hydrometer readings at 60° F. are of little value. For data at higher concentrations and temperatures see following tables.

TABLE 7-9. CORRECTIONS FOR CALCIUM CHLORIDE HYDROMETER READINGS

(Table 7-8 is based upon specific gravities strictly at 60° F. When hydrometer reading is made at a temperature other than 60° F., it must be corrected as shown in the following table, or the brine under observation must be brought to 60° F. before taking the reading.)

Hydrometer Reading	Corrections to be applied to hydrometer readings of calcium chloride solutions at various temperatures, using a hydrometer calibrated at 60° / 60° F.										
	0°F −17.8°C	10°F −12.2°C	20°F −6.7°C	30°F −1.1°C	40°F +4.4°C	50°F +10°C	60°F +15.6°C	70°F +21.1°C	80°F +26.7°C	90°F +32.2°C	100°F +37.8°C
1.000					.002	.001	No Corrections	.001	.002	.004	.005
1.010					.002	.001		.001	.002	.004	.005
1.020					.002	.001		.001	.002	.004	.006
1.030				.003	.002	.001		.001	.002	.004	.006
1.040				.003	.002	.001		.001	.002	.004	.006
1.050				.004	.003	.001		.001	.003	.004	.006
1.060				.004	.003	.001		.001	.003	.005	.007
1.070				.004	.003	.002		.001	.003	.005	.007
1.080				.004	.003	.002		.001	.003	.005	.007
1.090				.005	.003	.002		.001	.003	.005	.007
1.100				.005	.003	.002		.001	.003	.005	.007
1.110			.006	.005	.004	.002		.002	.003	.005	.008
1.120			.006	.005	.004	.002		.002	.003	.006	.008
1.130			.006	.005	.004	.002		.002	.004	.006	.008
1.140			.007	.006	.004	.002		.002	.004	.006	.008
1.150			.007	.006	.004	.002		.002	.004	.006	.008
1.160		.009	.007	.006	.004	.002		.002	.004	.006	.009
1.170		.009	.008	.006	.004	.002		.002	.004	.006	.009
1.180		.010	.008	.006	.004	.002		.002	.004	.007	.009
1.190		.010	.008	.007	.005	.003		.002	.004	.007	.009
1.200	.011	.010	.003	.007	.005	.003		.002	.004	.007	.009
1.210	.012	.011	.009	.007	.005	.003		.002	.005	.007	.010
1.220	.012	.011	.009	.007	.005	.003		.002	.005	.007	.010
1.230	.013	.011	.009	.007	.005	.003		.002	.005	.007	.010
1.240	.013	.011	.009	.007	.005	.003		.003	.005	.008	.010
1.250	.013	.012	.010	.008	.005	.003		.003	.005	.008	.010
1.260	.014	.012	.010	.008	.005	.003		.003	.005	.008	.011
1.270	.014	.012	.010	.008	.005	.003		.003	.005	.008	.011
1.280	.015	.013	.010	.008	.006	.003		.003	.005	.008	.011
1.290	.015	.013	.011	.008	.006	.003		.003	.006	.008	.011
1.300	.015	.013	.011	.008	.006	.003		.003	.006	.009	.011
1.310	.016	.014	.011	.009	.006	.003		.003	.006	.009	.012
1.320	.016	.014	.011	.009	.006	.003		.003	.006	.009	.012
1.330	.017	.014	.012	.009	.006	.003		.003	.006	.009	.012
1.340	.017	.015	.012	.009	.006	.003		.003	.006	.009	.012
1.350	.018	.015	.012	.009	.006	.003		.003	.006	.009	.012
1.360			.013	.009	.006	.004		.003	.006	.010	.013
1.370				.010	.007	.004		.003	.006	.010	.013
1.380					.007	.004		.003	.007	.010	.013
1.390						.004		.004	.007	.010	.013
1.400						.004		.004	.007	.010	.013
1.410								.004	.007		

Temperatures below 60° F.
Observed Hydrometer Reading *minus* Temperature Correction = Specific Gravity at 60°/60° F.
Temperatures above 60° F.
Observed Hydrometer Reading *plus* Temperature Correction = Specific Gravity at 60°/60° F.

TABLE 7-10. BRINE CONCENTRATIONS AT OTHER THAN 60° F.

(The following tables are included for convenience in determining concentrations of calcium chloride solutions at temperatures other than 60° F., using a hydrometer calibrated at 60°/60° F. Vacant spaces indicate that the solutions contain suspended crystals at these temperatures which make hydrometer readings of little value.)

	Hydrometer readings of calcium chloride solutions at various temperatures, using a hydrometer calibrated at 60°/60°F.										
% $CaCl_2$	0°F —17.8°C	10°F —12.2°C	20°F —6.7°C	30°F —1.1°C	40°F +4.4°C	50°F +10°C	60°F +15.6°C	70°F +21.1°C	80°F +26.7°C	90°F +32.2°C	100°F +37.8°C
0					1.002	1.001	1.000	0.999	0.998	0.996	0.995
2					1.020	1.019	1.018	1.017	1.016	1.014	1.012
4				1.037	1.036	1.035	1.034	1.033	1.032	1.030	1.028
6				1.056	1.055	1.053	1.052	1.051	1.049	1.048	1.046
8				1.073	1.072	1.071	1.069	1.068	1.066	1.064	1.062
10				1.092	1.090	1.089	1.087	1.086	1.084	1.082	1.080
11				1.101	1.099	1.098	1.096	1.095	1.093	1.091	1.089
12			1.111	1.110	1.109	1.107	1.105	1.103	1.102	1.100	1.097
13			1.121	1.120	1.119	1.117	1.115	1.113	1.112	1.110	1.107
14			1.131	1.130	1.129	1.127	1.125	1.123	1.122	1.119	1.117
15			1.142	1.141	1.139	1.137	1.135	1.133	1.131	1.129	1.127
16			1.152	1.151	1.149	1.147	1.145	1.143	1.141	1.139	1.137
17		1.164	1.162	1.161	1.159	1.157	1.155	1.153	1.151	1.149	1.147
18		1.174	1.173	1.171	1.169	1.167	1.165	1.163	1.161	1.159	1.156
19		1.185	1.183	1.181	1.179	1.177	1.175	1.173	1.171	1.169	1.166
20	1.197	1.196	1.194	1.193	1.191	1.189	1.186	1.184	1.182	1.179	1.177
21	1.207	1.206	1.204	1.202	1.200	1.198	1.195	1.193	1.191	1.188	1.186
22	1.218	1.217	1.215	1.213	1.211	1.209	1.206	1.204	1.202	1.199	1.197
23	1.231	1.229	1.227	1.225	1.223	1.221	1.218	1.216	1.213	1.211	1.208
24	1.241	1.239	1.237	1.235	1.233	1.231	1.228	1.226	1.223	1.221	1.218
25	1.252	1.251	1.249	1.247	1.244	1.242	1.239	1.236	1.234	1.232	1.229
26	1.264	1.262	1.260	1.258	1.255	1.253	1.250	1.247	1.245	1.242	1.240
27	1.274	1.272	1.270	1.268	1.265	1.263	1.260	1.257	1.255	1.252	1.250
28	1.287	1.285	1.282	1.280	1.278	1.275	1.272	1.269	1.267	1.264	1.261
29	1.298	1.296	1.294	1.291	1.289	1.286	1.283	1.280	1.278	1.275	1.272
30	1.311	1.309	1.306	1.303	1.301	1.298	1.295	1.292	1.289	1.287	1.284
31	1.322	1.320	1.317	1.315	1.312	1.309	1.306	1.303	1.300	1.297	1.295
32	1.334	1.331	1.329	1.326	1.323	1.320	1.317	1.314	1.311	1.308	1.305
33	1.346	1.343	1.340	1.337	1.334	1.331	1.328	1.325	1.322	1.319	1.316
34		1.355	1.352	1.349	1.346	1.343	1.340	1.337	1.334	1.331	1.328
35			1.364	1.360	1.357	1.354	1.351	1.348	1.345	1.342	1.339
36				1.373	1.370	1.367	1.363	1.360	1.357	1.354	1.351
37					1.381	1.378	1.374	1.371	1.368	1.364	1.361
38						1.390	1.386	1.383	1.379	1.376	1.373
39						1.402	1.398	1.394	1.391	1.388	1.385
40							1.410	1.406	1.403	1.400	1.397
41								1.420	1.416	1.412	1.408
42								1.433	1.429	1.424	1.420
43								1.446	1.441	1.436	1.431
44									1.453	1.448	1.444
45									1.465	1.459	1.454

TABLE 7-11. MIXING WEIGHTS FOR CALCIUM CHLORIDE

Hydrometer Reading	Pounds of flake calcium chloride per gallon of solution at various temperatures, and corresponding hydrometer readings at the same temperatures using a hydrometer calibrated at 60°/60°F.										
	0°F −17.8°C	10°F −12.2°C	20°F −6.7°C	30°F −1.1°C	40°F +4.4°C	50°F +10°C	60°F +15.6°C	70°F +21.1°C	80°F +26.7°C	90°F +32.2°C	100°F +37.8°C
1.000					0	0	0	0	0	0	0
1.020					.22	.23	.25	.26	.27	.30	.33
1.040				.48	.49	.50	.51	.53	.55	.57	.60
1.060				.73	.75	.77	.79	.80	.83	.85	.88
1.080				1.01	1.03	1.04	1.06	1.08	1.10	1.13	1.16
1.100				1.28	1.30	1.32	1.34	1.37	1.38	1.41	1.45
1.110				1.42	1.43	1.45	1.47	1.50	1.52	1.55	1.58
1.120			1.54	1.56	1.58	1.60	1.62	1.64	1.66	1.69	1.71
1.130			1.68	1.69	1.70	1.72	1.75	1.78	1.80	1.82	1.85
1.140			1.80	1.82	1.84	1.87	1.90	1.92	1.94	1.96	1.99
1.150			1.94	1.95	1.98	2.01	2.04	2.06	2.08	2.10	2.13
1.160			2.08	2.10	2.12	2.15	2.19	2.20	2.22	2.25	2.28
1.170		2.20	2.22	2.24	2.26	2.29	2.33	2.34	2.36	2.39	2.42
1.180		2.34	2.36	2.38	2.41	2.43	2.46	2.48	2.51	2.53	2.56
1.190		2.48	2.50	2.52	2.54	2.57	2.62	2.64	2.66	2.69	2.72
1.200	2.60	2.62	2.64	2.66	2.69	2.72	2.76	2.78	2.81	2.83	2.86
1.210	2.75	2.77	2.79	2.81	2.83	2.86	2.90	2.92	2.95	2.97	3.00
1.220	2.88	2.90	2.92	2.94	2.96	2.99	3.03	3.06	3.09	3.12	3.16
1.230	3.01	3.03	3.06	3.09	3.11	3.14	3.18	3.21	3.24	3.27	3.30
1.240	3.17	3.19	3.21	3.23	3.26	3.30	3.33	3.36	3.39	3.42	3.45
1.250	3.32	3.34	3.36	3.39	3.42	3.45	3.48	3.51	3.54	3.58	3.61
1.260	3.46	3.48	3.51	3.54	3.57	3.60	3.64	3.66	3.69	3.73	3.76
1.270	3.61	3.63	3.66	3.69	3.72	3.75	3.79	3.81	3.84	3.88	3.92
1.280	3.75	3.77	3.80	3.83	3.86	3.90	3.93	3.96	3.99	4.02	4.06
1.290	3.90	3.92	3.95	3.98	4.01	4.05	4.08	4.12	4.15	4.18	4.22
1.300	4.06	4.07	4.10	4.13	4.16	4.20	4.24	4.28	4.31	4.35	4.39
1.310	4.19	4.21	4.24	4.27	4.31	4.35	4.38	4.43	4.47	4.51	4.55
1.320	4.35	4.37	4.40	4.43	4.47	4.51	4.54	4.59	4.63	4.67	4.71
1.330	4.50	4.53	4.57	4.60	4.64	4.68	4.72	4.75	4.78	4.82	4.86
1.340	4.66	4.69	4.72	4.76	4.79	4.83	4.87	4.90	4.94	4.98	5.02
1.350	4.82	4.85	4.88	4.92	4.95	4.99	5.04	5.07	5.11	5.15	5.19
1.360		5.00	5.04	5.08	5.12	5.16	5.20	5.24	5.28	5.32	5.36
1.370			5.20	5.23	5.27	5.31	5.33	5.40	5.44	5.49	5.53
1.380				5.40	5.44	5.48	5.52	5.56	5.60	5.65	5.69
1.390					5.61	5.65	5.69	5.73	5.77	5.81	5.86
1.400						5.81	5.86	5.90	5.94	5.98	6.03
1.410							6.03	6.06	6.10	6.15	6.20
1.420								6.32	6.27	6.32	6.37
1.430								6.38	6.43	6.49	6.55
1.440								6.54	6.60	6.66	6.73
1.450									6.78	6.84	6.90
1.460									6.95		

Specific Heats of Calcium Chloride Brine. The specific heat of a liquid is the ratio of the quantity of heat required to raise the temperature of a unit weight of the substance one degree, to that required to raise the temperature of an equal weight of water one degree at any specified temperature.

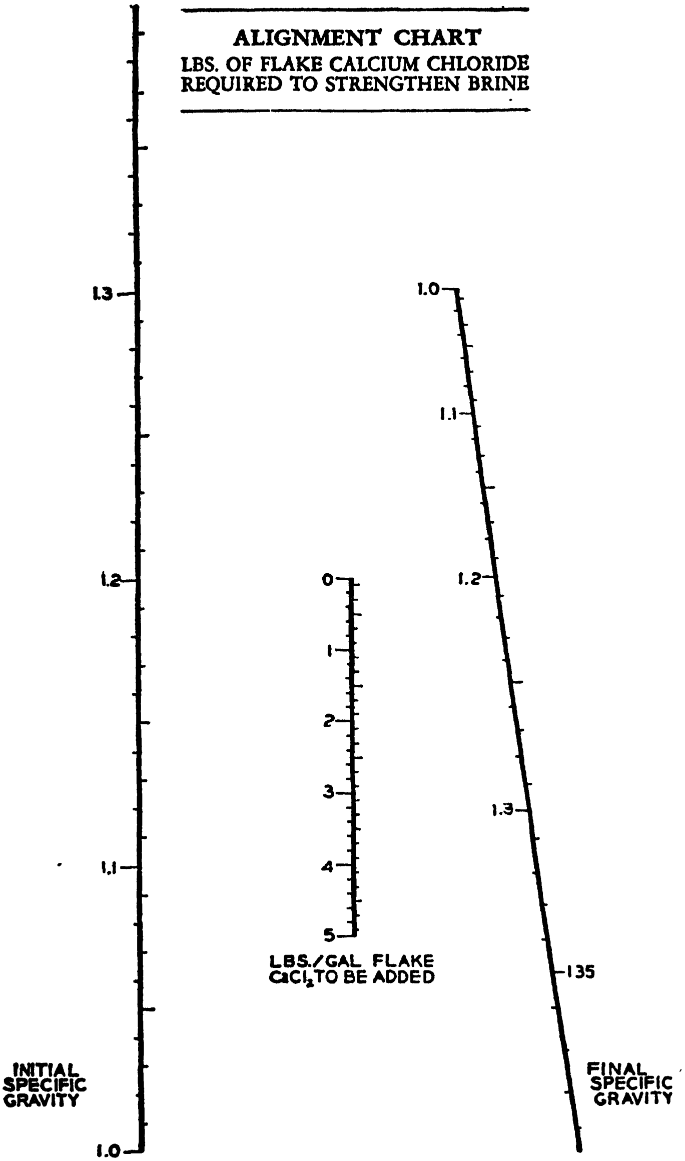
TABLE 7–12. SPECIFIC HEATS OF CALCIUM CHLORIDE BRINES

Temperatures		Specific Heats of Calcium Chloride Brines			
Fahrenheit	**Centigrade**	**At 1.175 Sp. Gr.**	**At 1.200 Sp. Gr.**	**At 1.225 Sp. Gr.**	**At 1.250 Sp. Gr.**
—22°F	—30°C				0.650
—13	—25			0.670	.653
— 4	—20		0.694	.675	.657
5	—15	0.721	.700	.680	.661
14	—10	.726	.705	.684	.664
23	— 5	.730	.709	.688	.667
32	0	.734	.712	.691	.671
41	5	.738	.716	.695	.674
50	10	.741	.719	.698	.677
59	15	.744	.722	.701	.680
68	20	.747	.725	.704	.683

TABLE 7–13. VISCOSITY OF CALCIUM CHLORIDE BRINE AT VARYING TEMPERATURES AND CONCENTRATIONS

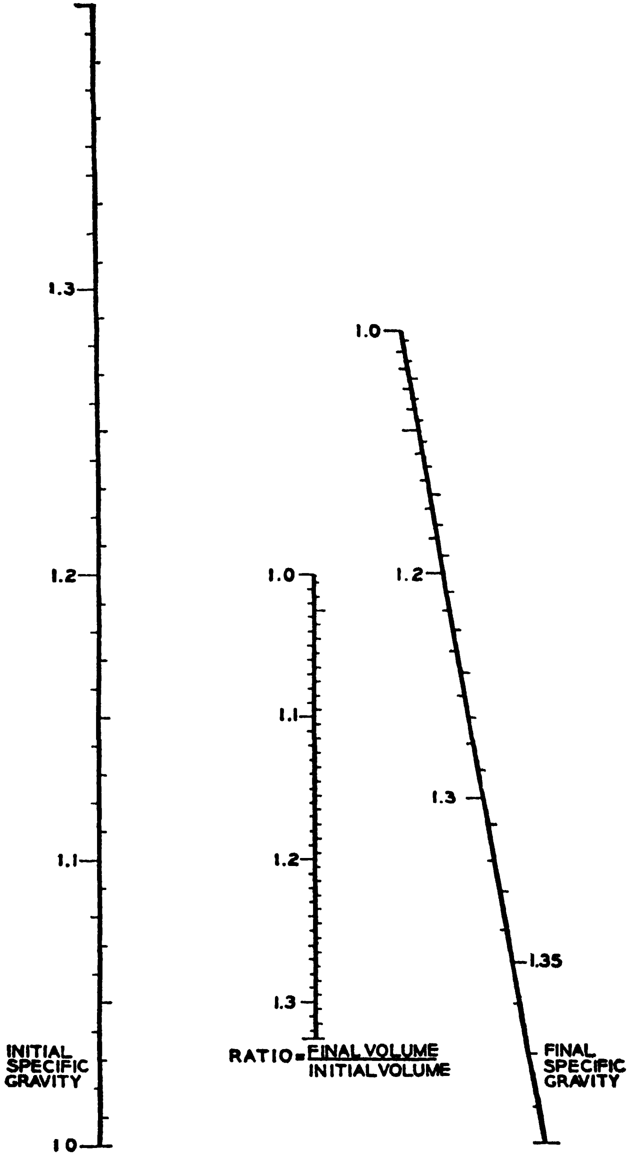
(From A.S.R.E. *Data Book*—1939–40)

% $CaCl_2$	Viscosity (in centipoises)					
	—13°F.	—4°F.	5°F.	14°F.	32°F.	50°F.
1.6					1.804	1.319
3.4					1.854	1.358
5.0					1.922	1.407
6.8					2.001	1.461
8.7					2.104	1.525
10.5					2.211	1.608
12.2					2.334	1.702
14.1					2.491	1.809
16.0				4.217	2.677	1.947
17.8				4.521	2.888	2.113
19.8			6.296	4.894	3.119	2.310
21.8		8.522	6.816	5.335	3.413	2.560
23.7	11.449	9.326	7.478	5.850	3.761	2.844
25.7	12.901	10.513	8.399	6.585	4.217	3.197
27.6	14.955	12.013	9.601	7.571	4.854	3.678
29.7		14.269	11.165	8.860	5.688	4.335
31.8		17.260	13.440	10.606	6.737	5.100
34.0					8.164	6.119
36.1					9.895	7.232
37.2					10.861	7.870



Alignment Chart

Pounds of flake calcium chloride required to strengthen brine.



Alignment Chart

Volume increase when strengthening calcium chloride brine.

SECTION VIII

HEAT TRANSFER

The transfer of heat energy from one surface or region to another surface or region due to a temperature difference between the two surfaces constitutes heat transmission. The Second Law of Thermodynamics prescribes that heat can be transferred from a high temperature surface to a low temperature surface but it cannot be moved from a low temperature surface to a high temperature surface unless some external work is done to aid the process.

Two very different conditions exist in the application of the principles of heat transfer. In much apparatus and equipment every effort is made to use material as the separating medium between the two surfaces that will conduct heat readily. The selection of the material, the design of the apparatus, the thickness of the walls and many other considerations are given to make certain that the resistance to the transfer of heat is at a minimum in equipment designed for high effectiveness in heat transfer. On the other hand, the designer and engineer may find it necessary in the same equipment or similar apparatus to prevent the heat from moving too rapidly from certain other surfaces or regions. The selection of material, the thickness of the walls and other considerations are now given to obtaining the highest possible resistance to heat flow from one surface to another.

The flow of heat from one area to another may be by *conduction*, *radiation* and *convection*. *Evaporation* and *condensation* are sometimes considered as special cases of convection or they may be considered as a separate process.

Radiation is the transfer of heat by means of electromagnetic waves, which travel in straight lines through a vacuum and through transparent material without heating the intervening medium. Any substance which possesses heat energy, emits radiant heat from its entire surface. The wave action is very closely related to the transmission of light. An opaque material which receives radiant energy may reflect a portion and absorb the remainder. Good reflectors absorb very little of the heat received while black bodies absorb nearly all. Thus, radiant heat leaves the sun and travels through the vacuum of space and through the atmosphere to reach the surface of the earth. In exactly the same manner, heat energy may be transmitted between two objects which are separated by a transparent material or from a warm wall to a colder wall near by.

Conduction is the transmission of heat from one molecule to an adjacent molecule by heat vibrations without the transfer of the molecules themselves. If one end of a bar of metal is heated, the temperature of the other end will be increased by means of the conduction of heat through the metal, although no migration of the molecules of metal has taken place.

High density materials have a greater conductivity than those in which the molecules are widely separated. The metals and heavy nonmetals with their dense structures have a much greater conductivity than the light materials like cork, cotton, sawdust and porous products. A perfect vacuum is a complete barrier to transmission by conduction, although radiant energy may traverse a vacuum without loss.

Convection of heat involves the transfer of heat from one region to another by an actual movement of the mass of material at a higher temperature to a region of lower temperature. It occurs in liquids and gases and in many instances by the impelled commingling of divided, crushed or broken-up solids.

Convection is called *free* or *natural* when by thermal changes circulation is brought about as in the movement of air currents through natural circulation effects. When the circulation is mechanically or physically compelled to occur as in the case of a circulating of hot water into a mixing vat or the dry mixing and cooking of cottonseed meal or the heating of a room by a fan operated unit heater it is termed *forced convection.*

Radiation Computations. When two bodies, one at a higher temperature than the other, are exposed to each other, a radiant exchange takes place from the hotter to the colder surface. The factors that should be considered in radiation are:

(1) The rate at which one body radiates or gives heat and the other body absorbs or receives heat is a function of the condition of the surfaces. The emissivity and the absorbing power of any surface can be definitely measured for radiant energy.

(2) Most polished metals have low emissivities; most nonmetals have high emissivities.

(3) The emissivity and the absorptive ability of surfaces is in proportion to the fourth power of the absolute temperature.

(4) Radiant energy is transmitted at velocities approaching those of light and the intermediate space through which it travels may not be changed in temperature.

The Stefan-Boltzmann Law states that the total energy radiated by a black body is proportional to the fourth power of the absolute temperature. In formula this is

$$E = 17.3 \times 10^{-10} \times T^4 \text{ Btu sq. ft. hr.}$$

Based on this law the radiation in Btu per hour of a large plane surface of emissivity E and absolute temperature T to a second large plane surface of emissivity E_1 and absolute temperature T_1 is

$$q = 17.3 \times 10^{-10} \times AE_1 \times E(T^4 - T_1^4).$$

Since $E_1 = 1$ for a black body then the above equation becomes

$$q = 17.3 \times 10^{-10} AE(T^4 - T_1^4).$$

TABLE 8-1. EMISSIVITY OF DIFFERENT SURFACES

(Black Body = 1)

Surface	*Emissivity at Room Temperature*
Asbestos board	0.95
Asphalt black roofing	0.95
Brick	0.92
Concrete	0.95
Plaster	0.91
Glass	0.93
Slate	0.75
Ice	0.65
Porcelain enamel, white	0.90
Brass, polished	0.095
Brass, dull plate	0.24
Copper, polished	0.03
Iron, smooth sheet	0.55
Galvanized sheet iron	0.23

Conduction Computations. The heat that flows by conduction from a region of high temperature to a region of low temperature is proportional to the temperature gradient between the two regions. Fourier gave the equation of the rate of the heat transmission across an area A in square feet of any homogeneous material as

$$q = kA\,\frac{dt}{dx} \quad \text{(in Btu per hr.)}$$

in which

q = Btu per hour transmitted through the material.
A = area in square feet through which the heat flows measured perpendicular to the heat flow.
k = the thermal conductivity in Btu, transmitted in one hour through one square foot of area through a homogenous wall of one inch thickness for a difference of 1° F.
$\frac{dt}{dx}$ = temperature gradient perpendicular to the area face.

For a path through a simple homogeneous wall the above equation becomes

$$q = k\,\frac{A}{x}\,(t_1 - t_2),$$

where x is the thickness of the homogeneous wall.

This equation is similar to the familiar equation in electrical current flow, $I = E/R$. In the heat equation above, q is the heat current, $t_1 - t_2$ is the difference in heat potential, k the reciprocal of the heat resistance, and the area and length of the path give the total resistance to the heat flow, such resistance being directly proportional to the length of path and inversely proportional to the area of the path.

The reciprocal of conductivity is resistivity or $1/k$. This is the temperature difference per inch of thickness necessary to make one Btu flow by conduction through one square foot of area of the homogeneous material through which the heat is flowing.

Many of the calculations in heat transfer by conduction also involve radiation and convection. When the heat flows from one medium to another through one or more intermediate resistances, the transmittance of the whole system perpendicular to the plane surfaces is the rate of heat flow per square foot of area divided by the difference in temperature of the two faces. This is called the *over-all coefficient of heat transfer*. It is usually designated by U and is also called the thermal *transmittance*.

The thermal *conductance* through a composite or nonhomogeneous material in Btu per hr. per sq. ft. per ° F. temperature difference for the over-all composite thickness used in construction is designated by C.

The *film* resistance between a wall surface and the surrounding fluid expressed in Btu per hr. per sq. ft. of surface per ° F. temperature difference is designated by $1/f$, where f is the film conductance.

The over-all thermal conduction, radiation and convection through an air space, expressed in Btu per hr. per sq. ft. of area per ° F. temperature difference is designated by a.

When consideration is being given:

To the over-all transfer of heat through a wall including radiation, conduction and convection, R is the reciprocal of U or $R = 1/U$.

To the resistance to conduction through a homogeneous wall, R is the reciprocal of k or $R = 1/k$.

To the resistance to conduction of a composite or non-homogeneous wall, R is the reciprocal of C or $R = 1/C$.

To the resistance of the film between the wall surface and the surrounding fluid whether this is resistance to heat transfer by *radiation*, *conduction* or *convection*, R is the reciprocal of f or $R = 1/f$.

To the resistance to thermal *conduction*, *radiation* and *convection* through an *air space*, R is the reciprocal of a or $R = 1/a$.

The total resistance to heat flow through any composite wall or between any two regions will equal the sum of all of the resistances in series in the path of heat flow or

$$R = r_1 + r_2 + r_3 + r_4, \text{ etc.}$$

R is also the reciprocal of the thermal transmittance or

$$R = \frac{1}{U} = r_1 + r_2 + r_3 + r_4, \text{ etc.}$$

In the class of heat-transfer applications where the design involves an insulating of the pipe or walls to decrease the heat-flow rate, the equations simplify themselves to readily workable formulas.

The transmittance of a uniform wall of conductivity k_1 under conditions where the film resistance on one side is f_1 and on the other side is f_2 will be

$$U = \frac{1}{\dfrac{1}{f_1} + \dfrac{x}{k_1} + \dfrac{1}{f_2}}.$$

The answer to this equation when computed gives the Btu per sq. ft. per hr. per degree difference between the two air temperatures on opposite sides of the wall.

The total heat flowing through the entire wall area A, with a temperature difference of $t_1 - t_2$ per hour, will then be

$$q = U(t_1 - t_2)A.$$

For a wall that is built of composite layers of different materials of conductivities k_1, k_2, k_3 and of thicknesses x_1, x_2, x_3 the equation for the transmittance becomes

$$U = \frac{1}{\frac{1}{f_1} + \frac{x_1}{k_1} + \frac{x_2}{k_2} + \frac{x_3}{k_3} + \frac{1}{f_2}}.$$

The value of q is found for the entire wall of composite surface by the same equation

$$q = U(t_1 - t_2)A.$$

Unit Thermal Conductivity, *k* Values. Values of the thermal conductivity of many substances are given in the Table 8–2. It can be readily seen that good conductors, such as copper and aluminum, have large k values and that good insulators, such as corkboard and still air, have small k values. For emphasis, it is repeated that the amount of heat in Btu per hour transferred by conduction through a plate of material one inch thick and having an area of one square foot, when there is a difference of temperature of 1° F. between the opposite surfaces of the plate, is the thermal conductivity of the substance, and is indicated by the letter k.

To compute the heat that will pass through one square foot of wall, when the area of the wall is known, the total heat passing through the wall may be determined. For instance, corkboard has a k value of 0.30, which means that 0.3 Btu per hr. will pass through one square foot of a wall 1 in. thick when the temperature on one side of the wall is 1° F. higher than on the other side. Since the amount of heat conducted is proportional to the temperature difference, ten times as much heat, which is 3.0 Btu per hr. per sq. ft., will flow through the wall when the temperature difference between the surfaces is 10° F. Increasing the thickness of the material decreases the quantity of heat conducted; thus, if the wall thickness is doubled only one half as much heat passes and

TABLE 8-2. THERMAL CONDUCTIVITIES AND DENSITIES

(British thermal units per hr., passing through one sq. ft. of a plate of material one in. thick, per °F. difference in temperature between the two faces)

	Density, lb. per cu. ft.	For Thickness of 1 In., Btu per sq. ft. per hr. per °F. k
INSULATING MATERIALS		
Asbestos fibers, packed	44	1.6
Asphalt roofing	55	0.70
Balsa wood	7-9	0.31-0.38
Chopped corn fodder	3	0.34
Corkboard, various grades	8-10	0.28-0.32
Cork, granulated	5	0.32
Cotton	5	0.42
Cottonseed hulls	5	0.31
Cypress lumber, cross grain	29	0.67
Eel grass mats	14	0.34
Frost or snow	6	0.65
Glass, window	160	5.0
Glass wool	4	0.29
Gravel	115	2.6
Gypsum plaster (plaster of Paris)	46	2.3
Hair felt	17	0.25
Ice	57.5	7.50
Kapok fibers	1	0.24
Magnesia, 85%	17	0.50
Mineral wool (slag or rock wool)	12	0.26
Mineral wool board, asphaltic binder	16	0.33
Oak lumber, cross grain	38	1.0
Pasteboard	43	0.49
Planer shavings, various woods	9	0.40
Redwood bark fiber	6	0.28
Rock wool	14	0.28
Sand, river dried	95	2.3
Sawdust, pine	12	0.40
Straw fibers	9	0.31
Sugar cane fiber board	15	0.33
Vermiculite	6.2	0.32
White pine lumber, cross grain	31	0.78
Water	62.3	4.3
Wood fiber board	14	0.33
Wool, pure	5	0.26
BUILDING MATERIALS		
Brick, soft	87	5.0
Brick, hard	140	9.2
Concrete, 1·2·5 *	170	6.3
Concrete, cinder aggregate	97	4.9
Stone masonry	170	12.0
Stucco	....	8.00
Tile, hollow clay 4 in. thick	.	0.50
METALS		
Aluminum	....	1400
Brass, 70% copper, 30% zinc	...	670
Copper	.	2700
Steel, mild	...	312
SURFACES AND AIR SPACES		
Surfaces		f
Inside surfaces—some ventilation	.....	2.00
Outside surfaces—15 mph air	...	6.00
Air Spaces—40° F.		k
¾ to 1½ in.	....	1.1

* Mix, 1 part Portland cement, 2 parts sand, 5 parts limestone.

if the wall were 6 in. thick only 1/6 of 3.0 Btu per hr. could be transferred through one square foot with a 10° F. temperature difference.

Example 1. Calculate the heat leaking through 6 in. of corkboard insulation on an ice tank 20 ft. x 10 ft. x 6 ft., when the tank is held at 12° F. and the earth which surrounds the tank is at 52° F.

Solution. The wall is 6 in. thick and thus one square foot will conduct 1/6 as much heat as a 1-in. plate when the temperature difference is 1° F. Numerically this is 1/6 of the k value for corkboard or $1/6 \times 0.3 = 0.05$ Btu per hr. per sq. ft. But the temperature difference is $52° - 12° = 40°$; thus, the wall will conduct 40 times as much heat as when the temperature difference is 1°. This is $40 \times 0.05 = 2.0$ Btu per hr. per sq. ft. Since the bottom, sides and ends of the tank are insulated, the area of the cork wall is 560 sq. ft.; thus, the total heat leakage is $560 \times 2.0 = 1120$ Btu per hr. through the cork insulation.

The actual arithmetical operation of solving this problem is to divide the k value by the wall thickness and to multiply this quotient by the temperature difference and then by the wall area. This operation may be indicated by the mathematical equation

$$q = \frac{k}{x} A(t_1 - t_2), \tag{1}$$

in which q is the heat conducted in Btu per hour, k is the thermal conductivity, x is the wall thickness in inches, A is the wall area in square feet, and t_1 and t_2 are the temperatures of the opposite wall surfaces. The equation may be used to calculate the heat conducted through a wall of any single substance, if the k value is known.

Example 2. Calculate the thickness of an oak wall which has the same insulating value as 2 in. of corkboard.

Solution. If the insulating values are the same, the amount of heat conducted by a square foot of either wall must be the same when the difference in temperature between opposite sides of the wall is the same. Thus, the equation reduces to $q = \frac{k}{x}$, since A is one square foot and $t_1 - t_2$ may be made equal to 1° F. Since each wall must allow the same quantity of heat to pass, the values of $\frac{k}{x}$ for each wall are identical. For the cork wall, $\frac{k}{x} = \frac{0.3}{2}$. For the other wall, $\frac{k}{x}$ is $\frac{1.0}{x}$, since the k value of oak across the grain is 1.0. Setting these values equal to each other

$$\frac{0.3}{2} = \frac{1.0}{x}$$

$$x = 6\tfrac{2}{3} \text{ in.}$$

When the wall is composed of several layers of material, each having a different k value, it is not possible to use the total thickness or any of the k values directly. Instead it is necessary to construct an imaginary wall in which each layer has the same ability to conduct heat as the corresponding layer in the actual wall. However, the material in the imaginary wall is to have a k value of 1.0, so that when the proper thickness of each layer has been determined, the total thickness may be used for x and 1.0 may be used for k in the equation $q = \frac{k}{x} A(t_1 - t_2)$.

Example 3. A refrigerated room adjoins an engine room. The partition wall is 9 in. of concrete, 3 in. of corkboard, and 2 in. of finish plaster and is 35 ft. long by 12 ft. high. The surface temperatures are 30° and 110° F., respectively. Calculate the heat leakage through this wall. The following values are taken from the table, k for concrete is 6.3, k for corkboard is 0.30 and k for finish plaster is 2.4.

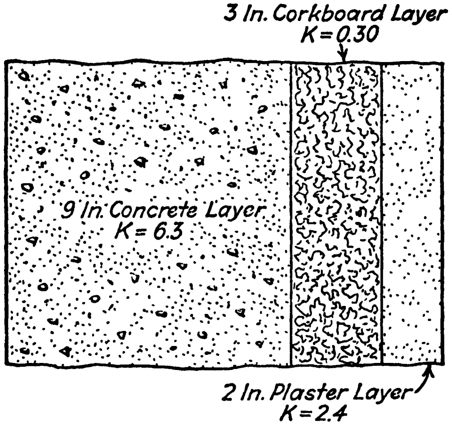


FIG. 8–1. Actual wall of concrete, corkboard and plaster.

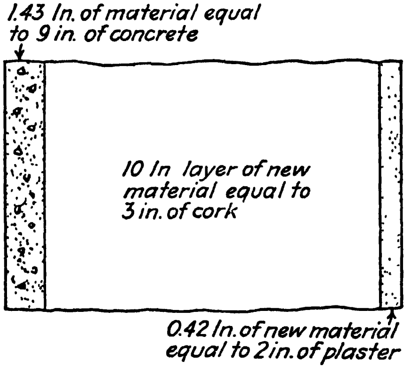

1.43 In. of material equal to 9 in. of concrete
10 In layer of new material equal to 3 in. of cork
0.42 In. of new material equal to 2 in. of plaster

FIG. 8–2. Imaginary wall of material having a k value of 1.0, which is equal to the actual wall. Total thickness, 11.85 in.

Solution. The k value of concrete is 6.3; thus, a layer 6.3 in. thick has the same ability to conduct heat as 1 in. layer of the new material having a k value of 1.0. Hence the thickness of new material equivalent to 9 in. of concrete is 9 divided by 6.3 in. In the same manner, the thickness equivalent to the cork layer and the plaster layer may be determined. The two walls are shown in Figures 8–1 and 8–2.

9 in. of concrete = 9 ÷ 6.3 in. of new material
3 in. of corkboard = 3 ÷ 0.3 in. of new material
2 in. of plaster = 2 ÷ 2.4 in. of new material

Thus, the total thickness of the new wall is $9/6.3 + 3/0.3 + 2/2.4 = 1.43 + 10.0 + 0.83 = 12.26$ in. of material which has a k value of 1.0.

The area of the wall is $35 \times 12 = 420$ sq. ft. and the temperature difference is $110° - 30° = 80°$. These values may now be substituted in equation 1

$$q = \frac{k}{x} A(t_1 - t_2)$$

$$q = \frac{1}{12.26} \times 420 \times 80 = 2740 \text{ Btu per hr.}$$

leakage through the wall.

It may be seen that the thickness of new material, which is equivalent to one of the layers of the actual wall, has been computed by dividing the thickness of the layer by its k value. Thus, if x_1, x_2, and x_3 are the thicknesses of the individual layers and also k_1, k_2 and k_3 are the respective conductivity of each material, the thickness x to use in equation 1 is

$$x = \frac{x_1}{k_1} + \frac{x_2}{k_2} + \frac{x_3}{k_3}.$$

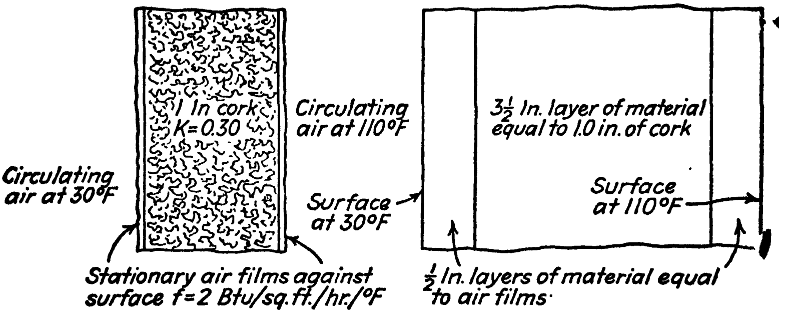
This method of calculation may be used to determine the heat transmission through a wall composed of any number of layers of different materials.

Fluid Films in Heat Transfer. Previous examples have specified that the surfaces of the wall through which heat is passing are maintained at certain temperatures, but these surface temperatures are not the same as the surrounding air temperatures. The truth of this statement is easily demonstrated by a bare pipe in which steam under pressure is flowing. The steam temperature is very high, yet the bare hand may be held fairly close to the pipe without discomfort; however, if the hand touches the pipe, a severe burn will result. Air is a poor conductor of heat; hence, the layer between the pipe and the hand does not conduct heat any faster than it is carried away by conduction through the skin and underlying flesh. If the hand touches the pipe, there is no layer of air, and heat is conducted directly to the skin.

Experimental work has shown that it is very difficult to obtain truly still air. Air in contact with a warm surface becomes less dense than the main body of the air and thus it will rise, whereas air in contact with a cold surface becomes more dense and will fall. A constant circulation is thus established and heat is transferred by convection. A thin layer of air adheres to the surface and it is necessary for heat to pass by conduction through this motionless layer or film before it can enter the moving air body.

Such a film offers considerable resistance to the flow of heat and is responsible for the difference in temperature between a surface and the surrounding air. It has been found that the heat conducted through such an air film is approximately 2 Btu per sq. ft. per hr. per degree F., when there is no wind or circulation of the air by artificial means. Hence, in calculating the heat leakage from the outside air to the inside air through a wall, it is necessary to take into account the effect of the air film on each surface.

Example 4. Calculate the heat transmitted from air at 110° F. through a 1 in. cork wall having an area of 100 sq. ft. to air at 30° F. The conductivity of the air film is 2 Btu per sq. ft. per hr. per ° F. (see Figure 8–3).


1 In cork
K=0.30
Circulating air at 110°F
Circulating air at 30°F
Surface at 30°F
Stationary air films against surface f=2 Btu/sq.ft./hr./°F
3½ In. layer of material equal to 1.0 in. of cork
Surface at 110°F
½ In. layers of material equal to air films

Wall of corkboard and air films. Equivalent wall of material having a k value of 1.0.

FIG. 8–3.

Solution. The conductivity of one air film makes it equivalent to ½ in. of material having a k value of 1.0. The 1-in. layer of cork is equivalent to 1/0.30 in. of material having a k value of 1.0. Thus, the wall and the two air films are equivalent to a layer of material having a k value of 1.0 and a thickness of $\frac{1}{2} + (1/0.30) + \frac{1}{2} = 4\frac{1}{3}$ in. Now using equation 1, it is calculated that,

$$q = \frac{1}{4\frac{1}{3}} \times 100 \times (110 - 30) = 1846 \text{ Btu per hr.}$$

The effect of air films does not greatly change the total amount of heat conducted through a thick wall of insulation, but the effect on the heat flow through a thin wall of metal or other good conductor is truly amazing.

Example 5. Compare the heat transmitted through one square foot of sheet steel ⅛ in. thick when the difference in temperature between the surfaces is 10° F. and through the same sheet when the air on one side is 10° F. colder than on the other and f for the air film is 2 Btu per hr. per sq. ft. per degree F.

Solution. In the first case there are no films and equation 1, $q = \frac{k}{x} A(t_1 - t_2)$, may be applied directly: k for steel is 312, x is ⅛ in., A is 1 sq. ft., and $t_1 - t_2$ is 10°; therefore,

$$q = \frac{312}{\frac{1}{8}} \times 1 \times 10 = 34{,}960 \text{ Btu per hr.}$$

In the second case it is necessary to convert the sheet and the air films to equivalent thicknesses of material having a k value of 1.0.

$$\text{Air film} = \tfrac{1}{2}\text{ in. of new material}$$

$$\tfrac{1}{8}\text{ in. of steel} = \tfrac{1}{8} \div 312\text{ in. of new material}$$

$$\text{Air film} = \tfrac{1}{2}\text{ in. of new material}$$

The total thickness of the equivalent wall is $\frac{1}{2} + (\frac{1}{8}/312) + \frac{1}{2} = 1.0004$ in. and

$$q = \frac{1}{1.0004} \times 1 \times 10 = 9.996\text{ Btu per hr.}$$

Thus, the plate will conduct 2500 times as much heat when the air films are absent. This fact is utilized in the so-called reflective insulations which are composed of alternating layers of air and thin metal sheets. A large number of air films are created by this construction and satisfactory insulation is secured even though the conductivity of the metal sheets alone is very great.

Heat Insulators. Much misinformation has been offered refrigeration engineers on heat insulation. This has not always been advanced through over-zealous manufacturers as is evidenced by the fact that sand is sometimes included in tables in the list of exceptionally good insulators.

Fine pure quartz sand has a very low factor of heat conductivity, but common river or quarry sand has a conductivity so great that it cannot be included in the class of good insulators.

Traditionally dead air space is an ideal insulation against heat transfer. Unfortunately, however, only a few instances can be found in the construction of large rooms and buildings where air space insulation is actually effective.

Heat transfer by convection and radiation, as well as by conduction, is involved in large air spaces. Unless the air spaces absolutely seal off all convection currents of air, the air space is no longer "dead air space," and the heat transfer is greatly increased.

Dead air space, to be highly effective, must be truly "dead" and prevent any appreciable flow of air. This makes it necessary to build up the air spaces into very small units if satisfactory results are to be obtained and the convection losses be reduced to a minimum.

Usually, the space given to the insulation can be mostly readily lowered in convection losses by filling the air space with cellular materials of low conductivity, thus shutting off the convection currents and not appreciably increasing the conductivity factors. Such cellular material is made up of millions of small air vaults with fibrous walls. These cellular vaults are so small that they prevent air movement and approach most nearly the ideal of a dead air space for insulation.

Requirements of Good Heat Insulation. The characteristics desirable in heat-insulating materials are:

(1) Low conductivity.
(2) Good handling characteristics.
(3) Resistance to decay, deterioration, and odor absorption.
(4) Extreme lightness to lower the weight in construction design.
(5) Ability to retain volume dimensions.
(6) Resistance to moisture.

Low conductivity. Conductivity, as practically interpreted, includes the heat transfer through the insulating material whether by conduction, radiation, or convection. Usually this is expressed in terms of the number of Btu that experimental tests have shown will pass through a piece of the material one square foot in area and one inch in thickness over a period of one hour for each degree *F.* difference in temperature of the two faces one inch apart.

Such conductivity measurements assume dry materials and as little as 5% of moisture will reduce the effectiveness of the insulation fully 50%.

Good Handling Characteristics. Many of our good insulating materials are very difficult to handle efficiently. This factor should always be given consideration in selection. For example, cork pipe covering is molded to shape at the factory and is readily applied in a short period of time after it is received by the purchaser. On the other hand, most of the wool felt and rock wool products must be built up on the piping on the job and require considerable time and effort.

Resistance to Decay, Deterioration, and Odor Absorption. The installation of a good insulation job requires considerable labor and expense. The interest, repair cost, and annual depreciation are of considerable consequence in making the business produce a profit. The insulation selected should be of a permanent nature. If it has any attraction for rodents or vermin, or readily absorbs odors of the products stored, its use should not be permitted.

Weight and Volume of the Insulation. Fortunately, most of the best heat insulators are very light in weight. Conduction being closely proportional to the density, the characteristics of lightness and good insulating properties are very closely related.

But volume dimensions introduce a more serious problem. Such heat insulators as sawdust, shavings, and loosely packed materials settle down year by year.

Moisture Resistant Insulation. It was indicated under the subject of conductivity that moisture reduces the effectiveness of the insulation very materially.

Many excellent heat insulators are composed of fibrous materials, which owe their effectiveness to the minute dead air spaces within the material. Infiltration of air into a wall composed of such insulation soon ruins it for refrigeration purposes. When a cold layer, which is below the dew point of the air, is reached, the condensed moisture will eventually fill the air spaces with water. This converts the insulation into a good conductor of heat, regardless of whether the fibers are waterproofed or not. For this reason, it is desirable to provide an effective seal against damp air on the outside of every refrigerated wall, unless the insulation itself is completely impervious to water vapor.

The moisture greatly affects the life of the insulation. When the binding resin of compressed corkboard becomes moisture soaked, the board soon disintegrates. Likewise, when rock wool or similar products lose their moisture-resisting properties, they become less effective as insulators.

Paraffins, asphalts and oils are often used to impregnate hairfelts, fibrous board and rock products to reduce moisture absorption. The better grades of cork are waterproofed by compressing them to the point that their own resins serve as a waterproofing binder.

Figure 8–4 illustrates how the moisture infiltrates into the insulation surrounding cold storage rooms and boxes under the typical operating conditions. If a freezer room is to be held at 0° F. and 80% relative humidity, the moisture that can be retained by each cubic foot of air at this temperature is less than 0.49 of a grain. At 100° F. and 75% relative humidity, the moisture that can be retained by each cubic foot of air on the outside will be 16 grains.

By virtue of the vapor pressure difference of the air on the outside and the inside, there will be a movement of this air through the porous wall materials from the outside to the inside. As the outside air passes inward the temperature drops on some gradient as is indicated in the graphical representation in the diagram. No water will be condensed from this air until it exceeds saturation. From the psychromatic chart this warm air with 16 grains of moisture will reach saturation when the air drops to a temperature of

90.6° F. Between this region and the cold face of the freezer storage room each cubic foot of air that will infiltrate from the outside to the inside must condense out the difference between 16. and 0.49 grains, or 15.51 grains of water.

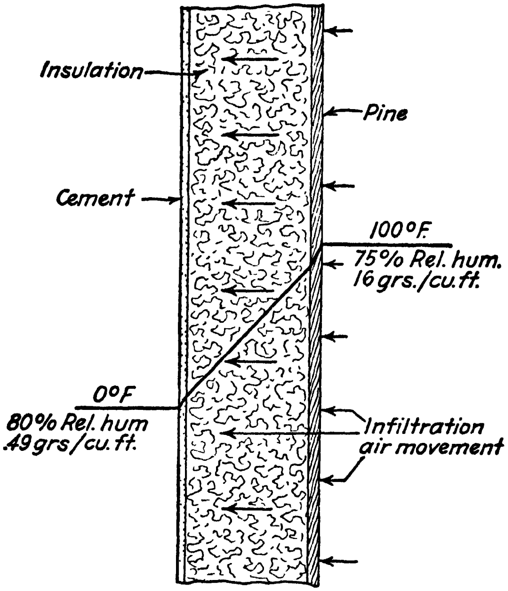


Fig. 8–4. Typical example of condensation in an unsealed insulated wall. Warm air of high moisture content moves into the zone of low temperature. Even at high relative humidities the holding capacity of cold air is very low. The warm air moves inward without depositing moisture until the humidity of the cooling air reaches 100%. This is the dew point. As the air moves further into the colder and colder zones more moisture drops out. By the time the migrating air reaches the storage space less than a half of a grain of moisture remains in each cubic foot of air that started in the path with 16 grains.

In the design of cold and freezer storage walls, provision is sometimes made to place waterproofed insulation next to the freezer room face and then use less moisture resistant materials on the outside face where there is little danger from condensation.

For example, a commercial box to operate at 35° F. was manufactured for installation on the Gulf Coast where summer temperatures of 100° F. dry bulb and 80° F. wet bulb were often experienced. For this condition it was found that three layers of asphalt-treated Celotex placed next to the inner face were sufficient to insure the dew point occurring in this waterproofed region. On the outer side of this Celotex 6 in. of yellow pine sawdust remained dry throughout the humid summer period.

Since the movement of air to cold storage and freezer storage rooms is from the warmer to the cooler region, it follows that this moisture migration to the insulated area can only be cut off by sealing the sections of insulation on the outside of each layer. This sealing can be done by either a metallic or a nonporous plastic material. In practice, the metallic shield may be placed on the outside and further sealing done by plastic odorless materials on the several layers between this metal shield and the face of the storage wall.

Much work remains to be done in the development of satisfactory methods of sealing insulation material that are used for refrigeration and air conditioning. Packaged material is available that is factory sealed, but in the placement process these sealed sections may become either cut or broken and this permits the air to enter the insulation and carry with it the undesired moisture. Many jobs of loose fill insulation are sold to the public for cold storage, entirely ignoring the moisture hazard. In a short period such insulated storage walls are in such a wet condition that holding the desired room temperatures is an expensive problem and in some instances overtaxes the capacity of the refrigeration compressors.

Economics Involved in Purchasing Heat Insulation. Experience has taught that many of the insulating materials available do not fulfill the requirements sufficiently to be called commercially practical.

From the standpoint of operation it is the usual problem of the refrigeration engineer to work up the figures comparing the first cost and the ultimate unit cost of the possible insulating materials that might be considered. This list usually includes several commercial corkboards, several commercial mineral-wool boards, a number of fibrous vegetable matter products, and sawdust and shavings.

Unless the structure is to be just temporary, the final decision usually rests between the corkboards, the mineral and glass wool, and hair felt products. It has been the author's experience that the word "temporary," as used in commercial work, means, at the least, ten years. Although the builder might be honest in his convictions that he will not need the structure more than two or three years, he usually postpones replacing it for a much longer period.

Corkboard is practically fireproof, light, easy to install, odorless, waterproof, odorproof and, when properly installed in surface cement, will provide a very compact and efficient cold-storage wall. The engineer must appreciate that the installation of any molded insulator is fully as important as the kind of material he uses. Every precaution should be taken to see that the sections are well supported, well set, and completely covered, if the best results are to be expected.

The mineral wool products may give more trouble in installation than the corkboard, but most of the characteristics of the mineral wool products are equal to those of the corkboard. It is light, odorless, and odorproof. Since they usually contain considerable paraffin, they will burn, but the burning is very slow. Like corkboard, it gives the best service when well set in a surface cement, and the appearance of the whole job is greatly improved if this precaution is taken.

Wool and other fibrous products require much more skill in application than do many of the molded forms of covering. It is usually economical to have them installed by the supplier.

Insulation Practice for Northern Climates. Exterior cooler walls on the northern exposures should have 4 in. of corkboard or equivalent; on the southern exposures, 5 in.

Exterior sharp freezer walls on the northern exposures should have 6 in. of cork and 7 in. on the southern exposures.

Walls between cold storage rooms should have 4 in. of cork or equivalent.

Walls between cold storage and sharp freezer rooms should have 5 in. of cork or equivalent.

Cooler floors should have 4 in. of cork plus the necessary protecting cement covering.

Freezer floors should have 6 in. of cork plus the necessary protecting covering.

The roof over the cooler space should have 7 in. of cork; over sharp freezer space 9 in. of cork.

Insulation Practice for Southern Climates. *All of the above values should be increased at least 1 or 2 in. of cork thickness or the equivalent.*

Termites and Insulation. Great care should be taken in storing all insulation of cellulose origin. Cork, Celotex, Masonite or similar cellulose materials, when stored in termite infested sheds, might become the feeding material of the termites.

When termite-infested insulation is installed in cold rooms the termites establish their tunnels to some point of moisture on the walls and live and multiply successfully in darkened storage rooms upon available cellulose foods and the wall moisture.

Attempts to destroy termites by bringing the room to temperatures as low as −10° F. will only retard their activity. They can endure very low temperatures.

Cases are on record where cold storage rooms six and eight floors above the ground level have become completely infested with termites by the introduction of cellulose insulation from termite-infested storehouses.

Insulation and Vibration. Vibration shortens the useful life of most of the existing insulating materials. With the increasing demand for insulating materials on railroad coaches, food transport trucks, automobiles, and ice delivery trucks, the development of insulating materials of high resistance to vibration is important.

Although many suppliers of the different forms of insulation insist that their product has solved the vibration problem, their judgment is based on relative tests. Even the best available insulation materials are of very limited life under vibration conditions.

Local Supplies of Insulation. By nature, insulation is very bulky. It requires a high transportation rate to make its handling profitable. As a result, too often the cost of insulation delivered is many times the cost of plant production.

Most regions possess the raw materials, either mineral, forest or agricultural, to produce high-grade insulation at a low price. Unfortunately many of the attempts at decentralizing the industry have been amateurish and impractical.

Much research on the economical production of high-grade insulation from existing materials is desirable in many regions. It offers the possibility of the use of very low value and waste raw material resources as the basis for an essential industry.

Metal Foils as Insulants. When metal foils are used for insulation, great care should be taken to insure that the heat insulating value of the bright surface is not reduced by the failure of the installation to provide for shutting off the convection currents. What is saved by utilizing the reflecting surface may be lost by convection heat losses.

Some users of metal foil have reported an electric condenser action of their walls and floor during thunderstorms. This can be overcome by proper grounding of the metal surface of the insulation.

The transmission coefficient C for a one-inch space with two layers of aluminum foil is .22.

Building Color. Most cold-storage buildings have a very dark surface on sides and roof. This is poor economy.

The reflecting of the sunlight from the building to keep the wall temperature as low as possible is as important as preventing the heat from moving from the outside wall surface to the cold-storage room. A considerable refrigeration tonnage can be saved by using light and aluminum painted surfaces. Black and dark wall and roof surfaces are an expensive luxury in cold-storage plant operation.

Hulkill * found that the radiation of heat to moving refrigerator cars is greatly affected by the nature and color of paints used in the exposed surfaces of the car. The temperature of a black car surface might average in the neighborhood of 10° F. higher than that of the surrounding air for a 24-hr. day in northern latitudes of the United States. The instantaneous or peak surface temperature of a black car surface may exceed the air temperature 30 or 40° during the summer hours of sunshine. Experiences with car surfaces in the South indicate that this peak difference may reach 50 or 60° in areas of intense sunshine during midafternoon of August.

Some unreported tests in Texas and California on black surface stationary storage roofs indicate temperature differences as high as 80° between the roof surface and surrounding air in midafternoon full sunshine. Black roof temperatures of 175° F. were observed.

The relative values of temperature differences due to solar radiation as suggested by Hulkill are:

Color of Paint	*Relative Excess over Air Temperature of Surface*
Black	100
Aluminum graphite—dark gray	90
Gray	85
Red	80
Old yellow	65
Aluminum metal	60
New yellow	60
White	50
Buff	45

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* W. T. Hulkill, *Refrigerating Engineer*, Vol. 23, 1932, pp. 225–233.

Queer * studied the effect of radiation in heat transfer through air spaces. He reported that ". . . with conventional building materials about 75% of the total heat transmission across enclosed vertical spaces is by radiation." Figure 8–5 shows the relation he found between heat diffusion and air space width and Figure 8–6 the relation between air space height and the heat transmission factor for an air space one inch in width.

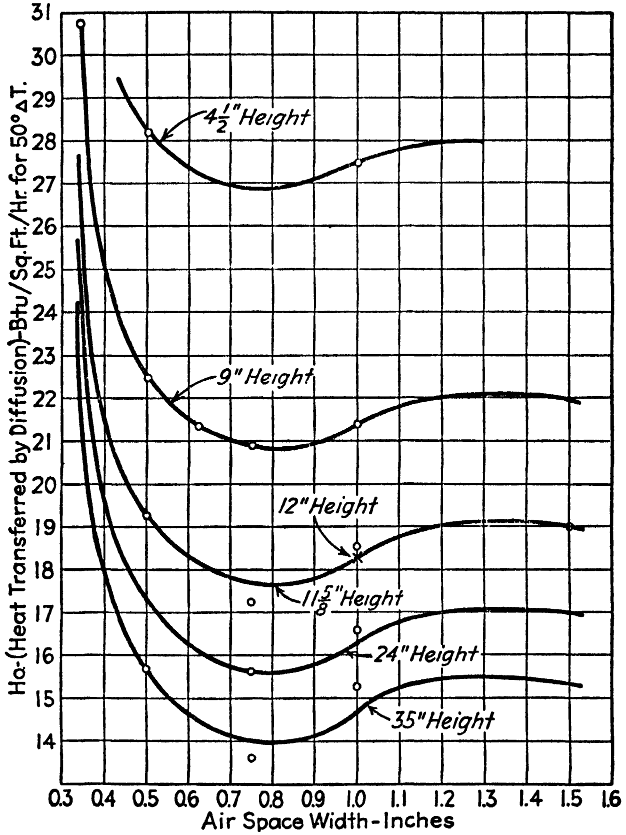

FIG. 8–5. Curves showing relation between heat diffusion and air space width and height.

In considering radiation heat losses or gains, differentiation

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* E. R. Queer, *Heating, Piping and Air Conditioning*, Vol. 3, 1931, p. 960.

must be made between solar radiation and radiation as within enclosed walls. Solar radiation is primarily within the visible spectrum and the colors as given above by Hulkill respond in the order tabulated by him for solar radiation. But the radiation within enclosed walls and rooms is more largely from the invisible infra red part of the spectrum. In the low temperature part of the spectrum all pigment paints generally have the same absorbing effect irrespective of color.

On the other hand, aluminum, tin and other polished metal or metal painted surfaces are excellent reflectors of the infra red part of the spectrum although they are not good reflectors of the visible spectrum rays.

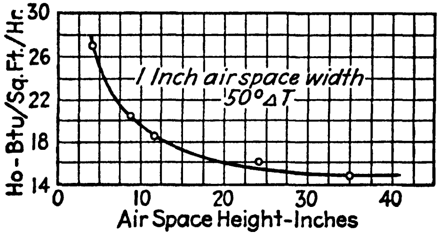

FIG. 8–6. Relation between air space height and heat transmission factor for one-inch air space.

It is obvious then that on the outside of a cold-storage house, a truck or a car, buff and other light-colored paints are preferable whereas on the inside of cold-storage rooms or ducts or cars, a finish in bronze or aluminum may be more effective.

Heat Transfer in Ice Melting. P. W. Scates* reported that (1) the rate of melting is proportional to the heat transfer from the air to the ice rather than the heat content of the air, (2) the rate of melting increases rapidly with increase in relative humidity and (3) the rate of melting increases rapidly with increase of air velocity (see Figure 8–7).

Willis and Short † found that the melting rate of block ice for natural convection could be expressed by the equation

$$q = UA(t_r - t_1) = (0.0744t'r - 0.0426tr + 0.82)A(tr - t_1),$$

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* P. W. Scates, "The Rate of Ice Melting," *Refrigerating Engineering*, July, 1931.

† A. H. Willis, B. E. Short and W. R. Woolrich, "Ice Melting and Freezing Rates," *Refrigerating Engineering*, May, 1940.

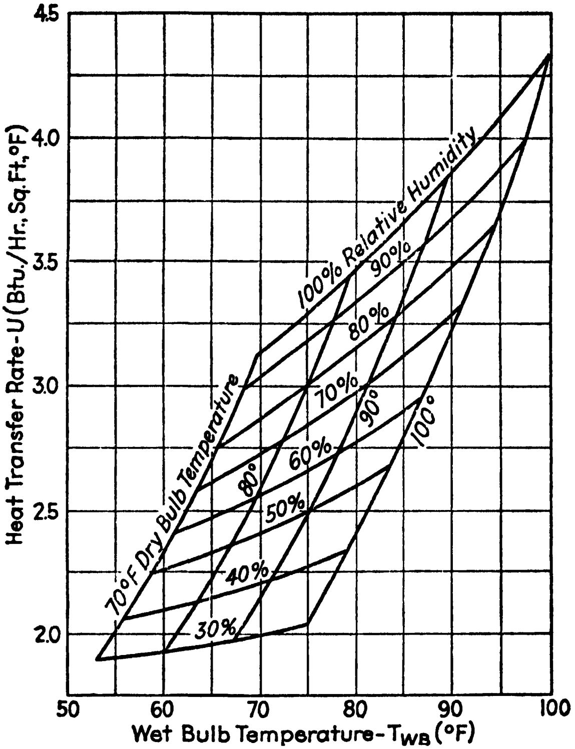

Fig. 8–7. Variation of overall transfer coefficient with temperatures of surrounding air and ice at 32° F.

where

q = total heat transferred to the ice blocks in Btu per hr.
U = over-all transfer coefficient = $0.0744t'r - 0.0426tr + 0.82$.
A = surface area of the ice block, sq. ft.
Δt = difference in temperature between surroundings and ice block = $(tr - t_1)$.
tr = dry bulb temperature of surrounding air.
$t'r$ = wet bulb temperature of air, °F.
t_1 = temperature of ice block, °F.

The studies of Willis and Short are indicated in the plotted values of over-all heat transfer coefficients at different relative humidities for normal room air as shown in Figure 8–7. The effect of humidity variations is very pronounced.

Mr. Paul Scates experimentally developed a series of curves to show the variation of heat transfer with air velocity and relative humidity. The curves of Scates are given in Figure 8–8. By interpolation of the Scates and the Willis and Short diagrams, the melting rate of a block of ice at various air velocities and humidities can be calculated. The results obtained by Willis and Short are for normal still air conditions in a room. The values by Scates are for air in movement impinging against one face of the ice block and this air sweeping past the adjacent four sides. Obviously the sixth face of the ice block would be subject to some air movement induced by the inspirator effect of the air sweeping by its four edges.

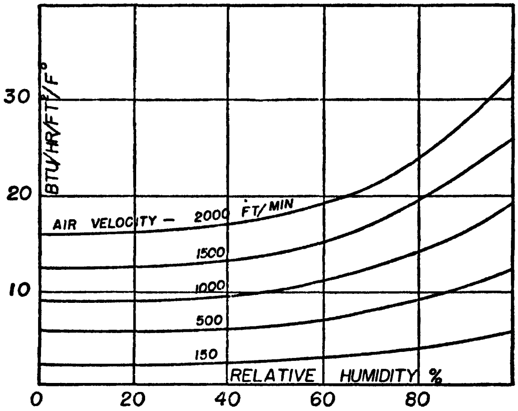

FIG. 8–8.

Heat Transfer through Pipe Walls. In heat transfer from a liquid or gas within a metal pipe to a liquid or a gas or a solid on the outside of this pipe, the factors effecting the over-all heat transfer are numerous. In the case of new metal pipe carrying a liquid on the inside of the pipe and another liquid moving over the outside of the pipe two different films have considerable effect.

An analysis of these films might be as follows:

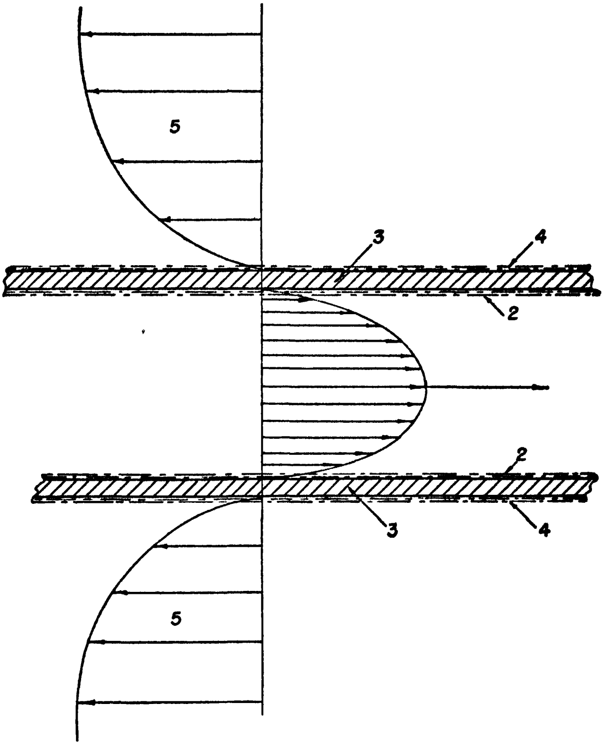

Fig. 8–9. Heat transfer processes in a condenser tube. 1. Heat transfer by fluid movement with velocity diagram as shown. 2. Film resistance inside of pipe, a conduction resistance. 3. Heat transfer by conduction through pipe metal wall. 4. Film resistance outside of pipe, a conduction resistance. 5. Heat transfer by fluid movement outside of tube with velocity diagram as shown.

In Figure 8–9 the parabola diagram represents the velocity of the liquid within the pipe. Heat is being carried by convection of the liquid mass moving in the direction indicated. At the pipe interior surface the velocity is equal to zero. The thickness of the film of liquid that will be at zero velocity at the wall will depend largely upon the viscosity of the liquid. Since the velocity of this film is zero heat must be transferred through it almost entirely by conduction.

Through the wall of the pipe the heat transmission will also be by conduction.

Immediately next to the outer surface the liquid on the outside of the pipe will have a film that has no movement. This film likewise will have a thickness dependent upon the viscosity of the liquid on the outside.

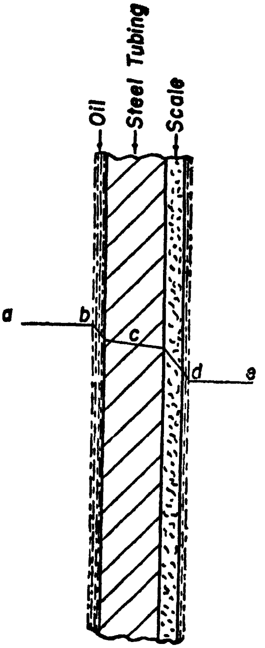

FIG. 8–10. Heat transfer process in condenser wall coated on inside with lime scale and outside with compressor oil. From *a* to *b*—heat transfer through fluid by convection. From *b* to *c*—resistance to heat flow by surface film and by oil heating. From *c* to *d*—resistance to heat flow by lime scale and by surface film. From *d* to *e*—heat transfer through fluid by convection.

The moving liquid on the outside of the pipe beyond the film will carry heat by convection as the mass moves by the pipe surface.

In this most simple system, therefore, there exists (1) heat moving within the pipe by convection, (2) heat moving through the film by convection, (3) heat moving through the pipe by conduction, (4) heat moving through the outside film by conduction and (5) heat moving beyond the film on the outside by convection. In addition there will most likely be some heat transfer by radiation from the inside and the outside surfaces of this pipe.

To increase the heat flow from the inside to the outside of this pipe or vice versa, many liquids deposit incrusting solids or oil coatings. Thus, the typical condenser tube in refrigeration eventually presents a condition indicated by the diagram in Figure 8–10. The heat-flow diagram represents graphically the resistance to heat flow involved in a typical vertical tube of a shell-and-tube condenser.

The resistance to the heat flow of the film will depend upon the substance which makes up the film. When a rapid movement exists on the part of the liquid or gas the film generally is reduced by the velocity and scrubbing action of the moving liquid or gas.

Gas films of the same thickness offer more resistance than liquid films but usually liquid films are of greater thickness than the gas film.

Mean Temperature Difference. When heat transfer problems involve heat transfer between two different regions or surfaces with uniform temperatures prevailing for each surface, then the value of the *temperature difference* is a simple subtraction problem. Where one or both of the heat transfer mediums are liquids, a temperature gradient will exist and vary along the length of the liquid travel.

The combinations that might exist are: Counterflow fluids exchanging heat as in Figure 8–11 (a); variable temperature hot fluids exchanging heat on the parallel flow principle as in (b); hot fluid with a decreasing temperature giving heat to a constant temperature gas or vapor mass as in (c); and a hot vapor or gas mass transferring heat to a flowing liquid whose temperature gradually rises as it is exposed to the higher temperature surface as in (d).

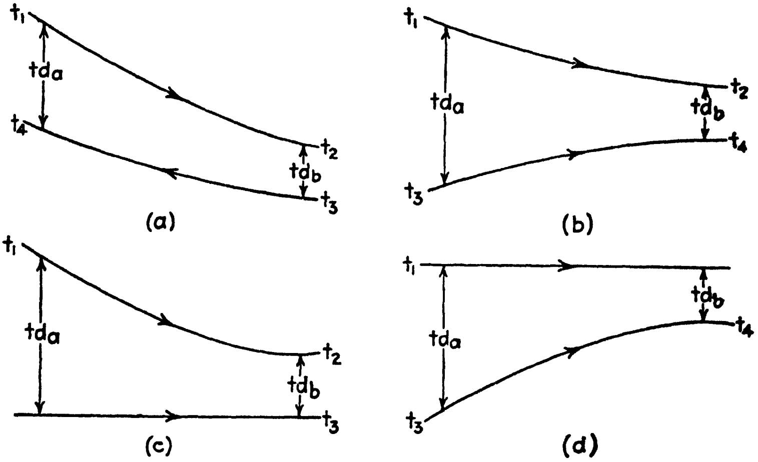

FIG. 8–11. Diagrammatic sketch of counter and parallel flow systems of heat transfer through walls.

In computing *mean temperature differences* the arithmetic or the logarithmic mean temperature difference may be used. If the temperature difference at one end of the heat transfer system is not more than 50% of the temperature difference at the other end of the system, the arithmetic mean temperature difference will be within 1%. For differences over 50%, the logarithmic mean is recommended.

The equation for the arithmetic mean of a calcium chloride brine cooler would be

$$\text{mtd.} = \frac{t_1 + t_2}{2} - t_3,$$

where

t_1 is the temperature of the brine entering the cooler,
t_2 is the temperature of the brine leaving the cooler,
t_3 is the temperature of the refrigerant.

For the determination of the logarithmic procedure this same problem would be

$$\text{mtd. (logarithmic)} = \frac{t_2 - t_1}{\log_e \left(\dfrac{t_3 - t_1}{t_3 - t_2}\right)}$$

$$\text{mtd. (logarithmic)} = \frac{t_2 - t_1}{2.3026 \log_{10} \left(\dfrac{t_3 - t_1}{t_3 - t_2}\right)}$$

$$\text{mtd. (logarithmic)} = .4343 \times \frac{t_2 - t_1}{\log_{10} \left(\dfrac{t_3 - t_1}{t_3 - t_2}\right)}.$$

As a general equation this might be written

$$\text{mtd. (logarithmic)} = \frac{td_a - td_b}{\log_{10} \left(\dfrac{td_a}{td_b}\right)} \times .4343,$$

where td_a and td_b are your temperature differences at each end of the system.

The value of *U* for Condensers and Coolers. The correct value of the coefficient of heat transfer for coils, condensers and coolers is difficult to select. When the coil is new, the outside and inside of the tubing or pipe is relatively clean. The value of k for metal pipe for the specific condition of service might be satisfactory for the testing period of the new coils. Within fifteen days these same coils will probably be somewhat corroded and may have film deposits of oil, or incrustating solids on the transfer surfaces. The new over-all coefficient of heat transfer U may be many per cent below the U value for new clean pipe.

The approximate values given herein are based on pipe used for some weeks or what the operator might reasonably expect from the coils in actual normal operation. The coefficient is given as U instead of k since it represents an over-all resistance to heat transmission or the normal coatings incident to the operation.

TABLE 8-3. OVER-ALL COEFFICIENTS OF HEAT TRANSFER

	Over-all Coefficient *U*			
EQUIPMENT AND APPLICATION:				
Atmospheric condensers	60–100			
Atmospheric-bleeder condensers	100–150			
Double pipe condensers—10° F. mtd.				
At 100 ft. water velocity	200			
At 200 ft. water velocity	320			
HORIZONTAL SHELL-AND-TUBE CONDENSERS NORMAL CONDITION:				
At 100 ft. water velocity	120			
At 200 ft. water velocity	160			
At 300 ft. water velocity	200			
At 400 ft. water velocity	230			
VERTICAL SHELL-AND-TUBE CONDENSERS:				
At 0.02 gal. cooling water per square foot tube surface	120			
At 0.04 gal. cooling water per square foot tube surface	160			
At 0.06 gal. cooling water per square foot tube surface	200			
At 0.08 gal. cooling water per square foot tube surface	230			
WATER COOLERS FREON FLOODED FIN TYPE 10° F. MTD.:				
Water velocity 150 ft. per min	80			
Water velocity 200 ft. per min	100			
Water velocity 250 ft. per min	115			
BAUDELOT COOLERS—BRINE TYPE:				
Milk	70–80			
Cream	60–65			
Water	70–80			
BAUDELOT COOLERS—DIRECT EXPANSION TYPE:				
Milk	60–70			
Cream	50–60			
Water	60–70			
BRINE COOLERS:				
Shell-and-tube type				
Velocity of brine, feet per minute	100	150	200	
U	75	95	110	
Double pipe type				
Velocity of brine, feet per minute	100	200	300	400
U	95	100	120	135
BRINE COILS IN ICE TANKS:				
Old style—trombone type coils—still brine	12			
Old style—trombone type coils				
Velocity of brine in feet per minute	20	30	40	
U	20	28	34	
New type—grid coils—good circulation				
Velocity of brine in feet per minute	30	100	150	
U	40	60	80	

SECTION IX

POWER DRIVES AND ECONOMICS

Steam Engines. For three decades the most popular prime mover in the refrigeration plant was the Corliss engine. Ice manufacturers and operating engineers learned to compare plants on the basis of the production of tons of ice per ton of coal burned at the boiler, and such a comparative basis was generally accepted as the practical standard.

Unfortunately, the size of nearly all steam-driven plants was small. This made it advisable to install noncondensing units in the majority of plants. The performance economy was relatively low, but the simplicity of operation and low maintenance expenditures of the low-speed Corliss drive made it a favorite with both manufacturers and users.

With the long-stroke, slow-speed, steam-driven units, high volumetric efficiencies were readily obtainable. The fundamental equation for net volumetric efficiency of ammonia compressors is made up of two component efficiency factors, which in equation form reads:

$$e_v = e_s \times e_c,$$

in which

e_v = net volumetric efficiency.

e_s = volumetric efficiency computed on the basis of the effective superheating during compression.

e_c = volumetric efficiency computed on the basis of the clearance.

Interpreted, this formula states that the net volumetric efficiency is equal to the product of the volumetric efficiency due to superheating and the volumetric efficiency due to clearance. The superheating effect is usually greater at high speeds than at low speeds, and this gives higher values of e_s for slow-speed machines.

The ratio of the clearance volume to the total cylinder volume is greater on short-stroke than on long-stroke machines, and this gives a higher value to e_c on the long-stroke machine. Therefore, any attempt to change from slow-speed, steam-driven units to the high-speed, electric-driven units has to be made with some sacrifice in net volumetric efficiency of the refrigeration machine, as both e_s and e_c are lowered in value.

Fortunately for the designers of high-speed ammonia compressors, vertical single-acting machines can be used. The vertical single-acting machine has always offered greater possibilities for high volumetric efficiencies than the horizontal double-acting ammonia compressor. Vertical machines could be made with false heads, and thus permit very small clearances, but the horizontal double-acting machine could not be easily designed to meet these conditions. Although the designers of steam-driven machines have met this situation by using vertical compressors with horizontal engines, it has involved an expensive construction. Thus, while the vertical slow-speed, single-acting, steam-driven ammonia compressor has given high volumetric efficiencies, the machine cost has been high, and usually the steam economy relatively low. Its electrical competitor has had to sacrifice something in both volumetric efficiency and length of life, but the cost of equipment and space required have been greatly reduced.

The other economic reason for the general acceptance of the electric drive in ice plants has been the almost total swing to the production of raw-water ice. With the ushering in of the manufactured ice business in the early eighties, there came a general demand for an ice as clear as, or clearer than, the natural river or lake ice. The answer was distilled-water ice. White ice is caused by the presence of air, and the boiling or distilling of the water was adopted as the almost universal remedy.

The idea of furnishing distilled-water ice was a boon to the ice business. To the public mind, distilled water meant absolute purity. That much of this purity was questionable, anyone who has been associated with the growth of the ice business must realize. To the writer, who has had unusual opportunity to watch the development of the ice business, there is no question that the raw-water supply in the average American city is far safer than the distilled water of the old type of ice plant.

Discovery and subsequent almost-universal adoption of methods of producing clear ice by circulating compressed air through the freezing water eliminated the distilled-water plant from the field. Without the need of condensed exhaust steam for the distilled water, there was no real need for boilers in the ice plant, as all other features of the business could be handled electrically. This development was the greatest single factor in the introduction of the electric-driven ammonia compressor.

Internal Combustion Engine Drives for Refrigeration Plants. For cold storage, ice production, locker storage and general refrigeration plants the Otto and the Diesel cycle oil engines are most serviceable as a stand-by unit. In some of the smaller cities that are removed from large electrical distribution systems, and even in some cities where electrical power is available but is sold at prohibitive rates, either the Otto or the Diesel engine may be found to be most economical as the principal engine, and as well for stand-by service.

In accepting the responsibility for providing uniform low temperature for the storage of perishable products, one of the first requirements for a successful storage plant is dependable power. Where this cannot be guaranteed by the electrical suppliers, it is recommended that a stand-by emergency power supply be furnished by either Diesel or other engine power. If the electrical power is not dependable, it is advisable to install both the principal power source and the stand-by of Diesel or other oil power.

For the smaller installations such as locker plants, the gasoline engine with full automatic controls is most desirable. Diesel engines are not generally available in capacities below 30 hp.

Many installations for providing ice by Diesel-driven compressors have been made within the United States, and even a much larger number of marine plants have been put into operation.

With the great impetus given the Diesel engine by the widespread adoption of this type of unit for merchant marine and naval applications during World War II, a decided increase in Diesel-operated refrigeration plants can be expected in the decade ahead.

Classification of Internal Combustion Engines. Internal combustion engines may be classified by several methods. Classification may be by the fuel burned, such as kerosene, butane, gasoline, gas or oil; by cylinder arrangement, as horizontal, radial, vertical, opposed, etc.; by type of cycle, such as Otto, Diesel, etc.; by the number of cylinders, as single cylinder, multi-cylinder; and by application, such as tractor, automobile, airplane, marine, stationary, etc.

The internal combustion engine may be of low, medium or high pressure. The low-pressure engines are those that generally do not exceed compressions of 150 lbs., and an explosion pressure of 250 lbs. The injected fuel is sprayed onto a hot bulb or a hot plate where it is heated and vaporized; with the aid of the heat of compression the fuel charge is ignited and performs the work of the engine power stroke.

The medium-pressure engines develop a compression pressure of 250 to 350 lbs. per sq. in., then the fuel is injected at the end of the power stroke. The explosion will raise the pressure to 400 to 500 lbs. per sq. in.

The high-pressure, more commonly called Diesel engine, may be either a four-stroke or a two-stroke cycle engine. The charge of air is compressed in the cylinder to approximately 500 lbs. per sq. in., which results in a temperature of probably 1000° F. At the end of this stroke the fuel oil is fed into this hot compressed air by a high-pressure pump, and a slow ignition results.

Diesel fuel pumps usually meter the oil fed to the cylinder in proportion to the power needs, and this makes possible a very close control on the fuel used. The fuel economy of the Diesel engine is usually much superior to that of the Otto engine cycle.

High-speed and Low-speed Diesels. In the early development of the Diesel engine within the United States, relatively low speeds were used. With the need for the Diesel engine to meet the competition with electric motors and Otto-cycle gasoline engines, especially in portable equipment such as the truck, the tractor, the motor boat, and packaged industrial units of all kinds, high speeds became very necessary. Today, many high-speed Diesels are being marketed within the North American continent and many more can be expected. Diesel engines are now offered with as low a weight factor as 10 lbs. of engine weight per indicated horsepower.

TABLE 9–1. DIESEL FUEL GRADES
(A.S.T.M. 1941)

Grade	Flash	Carbon Residue, Per Cent by Wt.	Ash, Per Cent by Wt.	Pour Point, °F.	Sulphur	Cetane	Type
1	100	. .	0.01	0	0.5	50	High speed
2	140	0.20	0.01	20	1.0	45	High speed
3	140	1.00	0.02	35	1.5	35	Medium speed
4	140	3.50	0.05	35	2.0	30	Low speed

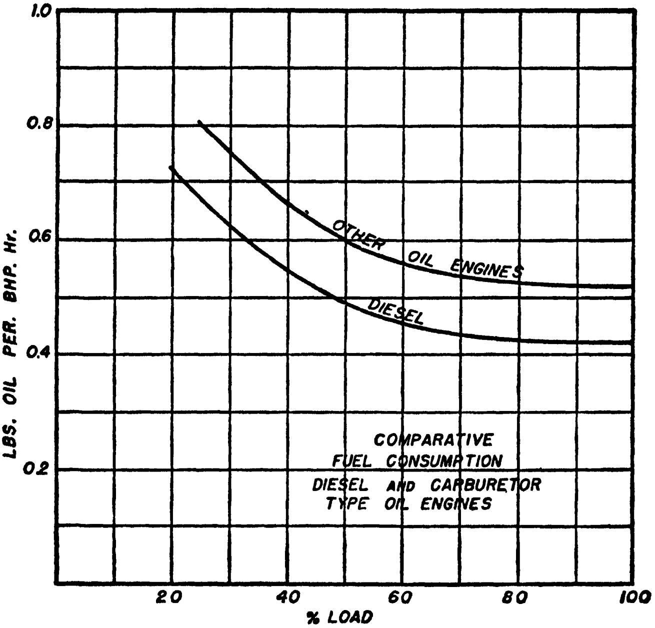

FIG. 9-1.

At high speeds the fuel economy is appreciably improved for both Otto and Diesel cycle engines. As is indicated on the comparative fuel graphs, the fuel consumption economy of the Diesel is somewhat better than that of the Otto. Much of this is due to the closer control of the fuel delivered to the Diesel by the metered fuel injection.

ELECTRIC MOTOR REFRIGERATION DRIVES

Advantages offered by electric drive for compressors are:

(1) Cost less to equip plant per ton of ice capacity.
(2) Occupy less space.
(3) Can be operated with less plant labor.
(4) Operating expense is nearly proportional to output.
(5) Greater flexibility in operation.

The disadvantages are:

(1) High speed results in lower volumetric efficiency of compressor.

(2) High speed involves more repair expense and shorter life of equipment.

Electric Motor Selection. The first step in the selection of motor drives is to decide between direct and alternating current as the power source. In many localities this decision will be made readily if power is to be purchased, since the available power will probably be the most economical.

If power is to be generated by the owner, then the three-phase electric drive usually will be the most satisfactory. The cost of generation, the simplicity of distribution and the cost of electric motors of the alternating type is in favor of three-phase a-c power adoption.

Single-phase motors are not only more expensive but they are more subject to repair than three-phase motors. The cost of power distribution of single-phase motors is also greater than for three-phase frequencies.

In a-c frequencies, 60 cycles is the most common within the United States and Canada, although 25-cycle current is available in several large cities. Usually the supply of available motors in the stores of the North American area is predominantly 60-cycle three-phase. In England and Europe 50-cycle current prevails.

POWER CONSUMPTION COMPUTATIONS FOR DIFFERENT TYPES OF MOTORS

Direct-Current Power. While relatively few d-c motor drives are installed today because of the predominance of a-c central station power, conditions occasionally require a d-c installation.

In using d-c power, the current consumption can be computed directly from the ammeter and voltmeter on the switchboard by multiplying the amperes by the volts:

$$\text{Volts} \times \text{amperes} = \text{watts}, \quad \text{or} \quad E \times I = P$$

where

E = electromotive force (volts),
I = amperes,
P = power in watts.

The power in watts can be readily changed to kilowatts by dividing the watts by 1000, or

$$\frac{P \text{ (in watts)}}{1000} = P \text{ (in kilowatts)}.$$

Since most rates are made on the basis of *kilowatt-hours*, it will be necessary to multiply the reading in kilowatts by the time in hours to change it to kilowatt-hours.

$$P \text{ (in kilowatts)} \times T = P \text{ (in kilowatt-hours)}$$

where T = time in hours.

Problem 1. A 30-ton compressor running on a d-c motor shows a voltmeter reading of 220 volts and an average ammeter reading of 102 amperes for 39 hrs. During this time two hundred 310-lb. blocks of ice were made. How many kilowatt-hours were used per ton of ice made?

Solution. Since volts × amperes = watts, then

$$220 \times 102 = 22{,}440 \text{ watts.}$$

To change to kilowatts, divide by 1000, or

$$\frac{22{,}440}{1000} = 22.44 \text{ kw.}$$

Since this was an average requirement for 39 hrs., then the total kilowatt-hours used would be

$$22.44 \times 39 = 875.16 \text{ kwh.}$$

The amount of ice made was $200 \times 310 = 62{,}000$ lbs.
Reducing this to tons,

$$\frac{62{,}000}{2000} = 31 \text{ tons.}$$

To compute the tons made per kilowatt, divide 875.16 by 31. Or, $875.16 \div 31 = 28.2$ kwh per ton.

Problem 2. An ammeter reads 210 amperes and the voltmeter in the same circuit registers 115 volts. What power in kilowatts is being used at the time of reading?

Solution. The volts × amperes in this circuit will be

$$115 \times 210 = 24{,}150 \text{ watts.}$$

To reduce this to kilowatts, we will divide by 1000:

$$\frac{24{,}150}{1000} = 24.15 \text{ kw.}$$

Single-phase A-c Power. In measuring single-phase a-c power, a new term is introduced as compared with the calculations in d-c power. This new term is the *power factor*.

In measuring d-c power, the power used was determined by multiplying the amperes by the volts. This same procedure would be correct for single-phase alternating current, but the voltmeter and ammeter do not always indicate the true effective volts and amperes. This is caused by the inductive and the capacitive effect in an a-c system. The power formula for a single-phase a-c system will therefore be:

$$E \times I \times p.f. = P \text{ (in watts).}$$

Power Factor and Load Factor. Engineers often confuse the term *power factor* with *load factor* and use them indiscriminately.

The value of the power factor may vary from 40% or 0.40 under very bad conditions to near 100% or 1.00 under more ideal operating conditions. The low power factor does not indicate that the efficiency is appreciably lower than that at high power factor. The actual power purchased is based on the true kilowatts. But low power factor does introduce a bad operating condition by excessive heating and should be corrected if possible.

Load factor, as usually computed, is a ratio of the average kilowatts used over a stated period of time to the maximum demand as based on a maximum-demand meter reading. The period of time on which this maximum is based is important. A period so short as when an unusual rush of current caused by some very temporary disarrangement becomes the basis of computation would be manifestly unfair. Such a maximum is generally based on an average of the three highest loads maintained over a 5-, 10-, or 15-minute period during the month.

Problem 1. The average voltmeter reading on a single-phase motor is 222 volts. The average current reading is 91 amperes. The power-factor meter indicates a power factor of 81%. How much power is being used?

Solution. For single-phase circuits the power consumption is

$$E \times I \times p.f. = P \text{ (in watts).}$$

In the above problem

$$E = 222 \text{ volts.}$$

$$I = 91 \text{ amperes.}$$

$$p.f. = 0.81.$$

Then $222 \times 91 \times 0.81 = 16{,}363$ watts.

The power in kilowatts will be,

$$\frac{16{,}363}{1000} \text{ or } 16.363 \text{ kw.}$$

Problem 2. The single-phase voltage of a circuit is 440. The current reading is 200 amperes. The power-factor meter shows 55%. What is the indicated power load in kilowatts?

Solution. $E \times I \times p.f. = P$ (in watts). Then $440 \times 200 \times 0.55 = 48,000$ watts. The power consumption in kilowatts will be, therefore,

$$\frac{48,400}{1000} = 48.4 \text{ kw.}$$

Three-phase A-c Power. Most refrigeration compressors are driven by three-phase motors. Two general types are available. These are induction motors and synchronous motors.

Synchronous motors are to be preferred for most three-phase installations. The improvement which they give to power-factor conditions is very desirable to both the owner and to the company selling power. It is to their mutual interest to use synchronous drives.

The power equation for computing the power consumption from the voltmeter and ammeter reading of a three-phase circuit involves an additional term because of the three circuits involved.

The fundamental three-phase power equation is

$$E \times I \times \text{p.f.} \times 1.73 = P \text{ (in watts).}$$

TABLE 9–2. WIRE AND CURRENT TABLE FOR D-C MOTORS

Horse-power	110 Volts		220 Volts		440 Volts	
	Average Amps. at Full Load	Size of Wire Rubber Insulation	Average Amps. at Full Load	Size of Wire Rubber Insulation	Average Amps. at Full Load	Size of Wire Rubber Insulation
1	9	14	4.5	14	2.3	14
2	16	12	8	14	4	14
3	24	8	12	14	6	14
5	40	6	20	10	10	14
7.5	60	4	30	8	15	12
10	75	2	38	6	19	10
15	112	0	56	4	28	8
20	148	000	74	2	37	6
25	184	0000	92	1	46	5
30	220	250,000 *	110	0	55	4
40	290	400,000 *	145	000	73	3
50	360	500,000 *	180	0000	90	1
60	. .	. . . . .	220	250,000 *	110	00
75	.	. . .	275	350,000 *	138	000
100		. . .	365	500,000 *	183	0000
125	.	. . . . . .	450	700,000 *	225	250,000 *
150	.	. . . .	550	900,000 *	275	400,000 *

* Circular mils.

The value of E (volts) and I (amperes) may be taken as the reading on any one phase on the assumption that the load is balanced on all phases. The constant 1.73 is derived from the square root of 3, this being the mathematical relation between phases.

Problem 1. The balanced load on a three-phase circuit shows 220 volts per phase and 119 amperes on each leg. The power factor is 96%. What is the power consumption in 12 hrs.?

Solution. The formula for three-phase circuits is

$$E \times I \times p.f. \times 1.73 = P \text{ (in watts).}$$

Since

$$E = 220 \text{ volts,}$$

$$I = 119 \text{ amperes,}$$

$$p.f. = 0.96,$$

then

$$220 \times 119 \times 0.96 \times 1.73 = 43{,}479.7 \text{ watts.}$$

To reduce this to kilowatt hours over a 12-hr. period, we will have

$$\frac{43{,}479.7 \times 12}{1000} = 521.76 \text{ kwh.}$$

TABLE 9–3. WIRE AND CURRENT TABLE FOR THREE-PHASE A-C MOTORS

Horse-power	110 Volts		220 Volts		440 Volts	
	Average Amps. at Full Load	Size of Wire	Average Amps. at Full Load	Size of Wire	Average Amps. at Full Load	Size of Wire
0.5	4	14	2	14	1	14
1	7	12	3.5	12	2	14
2	12	8	6.0	12	3	14
3	18	6	9	10	4.5	14
5	30	6	15	10	7.5	12
7.5	42	5	21	8	10.5	12
10	58	3	29	6	14.5	8
15	80	1	40	4	20	8
20	110	00	55	3	27.5	6
25	122	000	66	1	33	5
35	...	...	86	0	43	4
50	. .	.	130	000	65	1
75	. .	.	190	300,000 *	95	0
100	...	...	250	500,000 *	225	000
150	. .	...	365	600,000 *	183	300,000 *
200	. .	...	475	800,000 *	238	400,000 *

* Circular mils

Problem 2. The voltage of a three-phase induction motor is 220 on each phase, with 63 amperes flowing in each phase. The power-factor meter indicates 90%. What power in watts is indicated?

Solution. For three-phase circuits,

$$E \times I \times p.f. \times 1.73 = P \text{ (in watts)}.$$

Since

$$E = 220,$$

$$I = 63,$$

$$p.f. = 0.90,$$

then

$$220 \times 63 \times 0.90 \times 1.73 = 21{,}580 \text{ watts}.$$

AMMONIA UNIPOWER CURVES, THEORETICAL AND ACTUAL, FOR COMPRESSION REFRIGERATION BY ELECTRIC DRIVE

Figure 9–2 gives the theoretical horsepower requirements for a given head and suction pressure, assuming dry and saturated suction gas conditions and adiabatic compression.

Problem. A compressor suction shows a gage pressure of 33 lbs. and a temperature of 20° F. The discharge pressure is 105 lbs. gage. Under saturated suction conditions and adiabatic compression, what are the theoretical horsepower requirements per ton?

Solution. 33 lbs. gage is equal to 47.7 lbs. abs. (add 14.7 lbs. to change gage pressure to absolute pressure).

105 lbs. gage = 119.7 lbs. abs.

The 47.7 lbs. abs. suction pressure on the ordinate intersects the ammonia saturation curve at 20° F. temperature as shown in Figure 9–2.

By projecting the 20° F. temperature line vertically to the 119.7 lbs. pressure line, the horsepower requirement per ton of refrigeration is read 0.5 hp.

Theoretical Values Corrected for Volumetric Efficiency. The capacity of all compressors is greatly reduced by failure to secure a 100% volumetric efficiency of the machine. Volumetric efficiency may be defined as the ratio of the amount that is actually discharged from the compressor cylinder to its actual cylinder displacement.

The volumetric efficiency is affected principally by:

(1) Clearance of the compressor.
(2) Leakage of the piston, piston rings and valves.
(3) Superheating of the gas.
(4) Speed of the machine.
(5) Design of the valves.

Seldom will the over-all volumetric efficiency exceed 75%. The values of Figure 9–3 are derived from those of Figure 9–2 by making this assumption. For example, consider the suction temperature of 20° F. and a head pressure of 119.7 lbs. abs. as previously determined. By checking on Figure 9–3 after making correction for volumetric efficiency, the horsepower requirements per ton can be read by interpolation as 0.667 hp.

Theoretical Values Corrected for Volumetric Efficiency and Mechanical Efficiency of the Compressor. When correction has been made, as above, for volumetric efficiency, the results obtained do not include any allowances for the friction of the pistons, bearings, piston rods, valve mechanisms, etc. Actually, to drive the mechanism idle would require some power input; and when driving it under loaded conditions, there must likewise be made sufficient allowance to overcome friction or mechanical losses.

These losses will vary from compressor to compressor, but with good design and well-loaded conditions the friction loss will probably approximate 12%.

Figure 9–4 is computed, therefore, from the values of the Figures 9–2 and 9–3 by dividing through the values of Figure 9–4 by 1.00 – 0.12 or 0.88. The resultant curves are therefore the unipower curves for the actual required mechanical input per ton of refrigeration.

If the same suction value is used as before, that is, 20° F. suction temperature, and the same discharge pressure of 119.7 lbs. abs., by interpolation of the curves, an input of 0.758 hp. is obtained.

Theoretical Values Corrected for Volumetric Efficiency, Mechanical Efficiency, and Electrical Efficiency. It is convenient to know just what electrical input is required per ton of refrigeration produced under different operation temperatures and pressures of suction and discharge. The average motor drive is assumed to have an efficiency of approximately 85%. Figure 9–5 is derived, therefore, from Figure 9–4 by making allowance for this electrical motor loss of 15%.

By the same procedure as adopted for the previous curves, follow through in Figure 9–5 the values considered in Figures 9–2, 9–3, and 9–4; that is, if we consider a suction temperature of 20° F. and a head pressure of 119.7 lbs. gage, the curves show by interpolation a power requirement of 0.89 hp.

SECTION X

TESTING THE REFRIGERATING PLANT

Factors Affecting Tonnage. Temperature-pressure curves of gases indicate the wide difference in operating characteristics of the commonly used commercial refrigerants. To be successfully used as refrigerants, however, each of these must be put through the same typical cycle. Pressures must be used that will supply the compressor with the refrigerant in gaseous form. Continuing on in the cycle, the pressures produced by the compressor must be such that the temperature of the gas is raised considerably above that of the available cooling water, otherwise condensation will not be possible at a working rate.

One ton of refrigeration = 288,000 Btu in 24 hrs.
One ton of refrigeration = 12,000 Btu per hr.
One ton of refrigeration = 200 Btu per min.
One ton of refrigeration = 3.33 Btu per sec.

After condensation is complete, the liquid refrigerant is ready for expansion by lowering its pressure through an expansion valve, or, what might be more correctly called the pressure-reducing valve. This lowering of pressure lowers the boiling point very greatly and makes possible the absorption of large quantities of heat as the refrigerant boils in the cooling coils, revaporizes and takes up the latent heat of vaporization from the surrounding brine or air.

In this cycle, common to each of the several refrigerants, the tonnage produced is dependent upon:

(1) The amount of refrigerant pumped through the system.

(2) The pressure and temperature changes through which the refrigerant passes.

The parts of the system in which heat is gained are: (a) In the receiver and the piping between the condenser and refrigerator, (b) in the refrigerator, (c) in the piping between the refrigerator and compressor, and (d) in the compressor.

The parts of the system in which heat is lost are: (a) In the jacket water of the compressor, (b) in the compressor-to-condenser piping, and (c) in the condenser.

The heat equivalent of the work of compression added to the heat taken up in the cooler and the piping between condenser and cooler, and cooler and compressor, represents the total heat taken up. This must equal the heat lost to the jacket water, to the compressor-to-condenser piping, and to the condensing water.

In this discussion, ammonia will be considered as the typical refrigerant, and the instructions given will apply specifically to ammonia systems. But the same general rules will apply to any of the other refrigerants.

At certain temperatures and pressure ranges both ammonia liquid and ammonia gas would be present in parts of the refrigerating system. The heat content of the known weight of the ammonia liquid or of ammonia gas can be readily ascertained from the tables of "Properties of Ammonia" developed by the United States Bureau of Standards.

But when ammonia is present in both the gas and liquid form, it is not sufficient to know how many pounds of ammonia are being pumped, and at what temperature and pressure. In order to determine the total heat, it would be absolutely necessary to also determine the per cent of gas and liquid present.

Since such a determination would be very difficult under operating conditions, it is advisable to operate the plant under conditions that will assure the engineer that ammonia gas and ammonia gas only exists at the point of pressure and temperature measurement at the suction side of the compressor. Likewise, he must know that at the point of measurement of the temperature and pressure between the receiver and the expansion valve that only liquid ammonia is present.

To bring about this condition at each of these two points, under test conditions, the plant is operated under a few degrees of superheat at suction and a few degrees of sub-cooling at the receiver. If superheat is present at the suction, then no liquid can be present. If a liquid is sub-cooled at the receiver, then all of the gas must be condensed. It is for this reason that the stipulation is made under "standard ton" test conditions that 9° F. of super-heat shall be present on the suction side, and 9° F. of sub-cooling shall be carried on the discharge side.

MEASURING AND WEIGHING AMMONIA

Various methods are used to measure the amount of ammonia pumped through the system. The method used will probably depend on the degree of accuracy required.

If conditions require a test of closer accuracy than 3%, the determination should be made by weighing the ammonia as it passes from the receiver to the expansion valve, or by measuring it by volume in tanks connected as auxiliary to the receiver.

If only an approximate test is desired, the ammonia may be metered or the amount pumped computed from the indicator card. If either of these two methods is used, certain assumptions are necessary.

Still another method that can be used, if brine is circulated, is to measure the amount of brine cooled and the temperature rise and specific gravity of the brine. The specific heat of brine can be obtained from tables of specific gravity and specific heats. The weight of the *brine circulated per hour*, multiplied by *specific heat* and this times the *temperature rise in the refrigerator* would give the value of the cooling effect produced.

How Ammonia Is Weighed. Ammonia can be readily weighed by connecting two cylindrical weighing tanks, as indicated in Figure 10–1, permitting first one tank and then the other to function as the ammonia receiver, and using the regular receiver as a header to supply the two weighing tanks. The piping used in this set-up, contrary to the usual instructions, should be standard weight high-grade steel pipe with a length of not less than 10 or 20 ft., depending upon the size of connecting pipe that is necessary to carry the ammonia. It is not necessary to use extra heavy piping for this connection as is often specified. The standard weight pipe is more flexible, and new pipe is sufficiently strong to withstand the ammonia pressures at the temperatures met at the receiver.

In detail, the weighing operation using the layout of Figure 10–1 would be as follows:

Under normal operation ammonia flows from the condenser to receiver *A* through valve 1, then through valve 6 to the evaporator or cooler by way of the expansion valve. When all is ready to start the test, one of the ammonia weighing tanks, say *C*, is partially filled by opening valves 5 and 3, with valve 7 tightly closed.

When the gage glass of tank *C* shows sufficient ammonia, valve 5 is closed and the ammonia in tank *C* weighed.

The test can now be started. Valve 6 is closed, and valves 4 and 2 opened for filling tank *B*, while valve 7 is opened to supply the expansion valve. Throughout the test, valves 3 and 2 remain open as equalizing valves to permit tanks *B* and *C* to fill and empty freely.

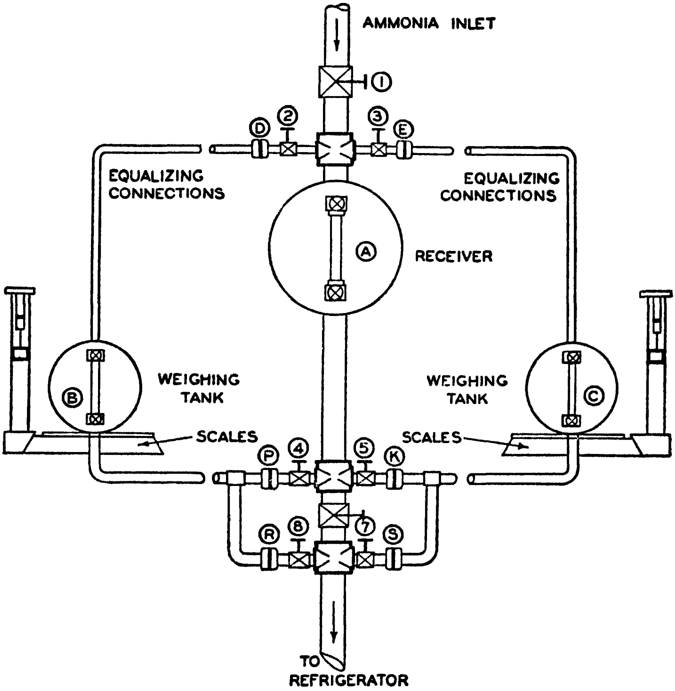

FIG. 10-1.

Tank *B* is filled, then weighed in the same manner as tank *C* after valve 4 is closed. When ready to change tanks, valve 7 is closed, and valves 8 and 5 opened to supply the expansion valve and tank *C*, respectively.

In closing the test, care must be exercised that all of the ammonia weighed has been discharged through the expansion valve.

In setting up the equipment and piping for this test, it is especially recommended that the ammonia unions indicated as *M*, *N*, *O* and *P* be used. This will permit attaching and detaching the measuring equipment without delay.

How Ammonia Is Measured Volumetrically. Volume measurements of ammonia can be made that are fully as accurate as the weighing method. If weighing tanks *B* and *C* in Figure 10–1 are replaced by vertical measuring tanks equipped with long gage glasses, the volume used can be correctly measured. The routine of filling these tanks is exactly the same as for weighing.

The data presented below giving a typical test of a 60-ton refrigeration plant have been collected on a plant in which the ammonia has been weighed as outlined in Figure 10–1. In addition to measuring the ammonia and the necessary ammonia temperatures, the amount of brine circulated has been metered and the temperature rise of the brine measured. This gives a check on the actual amount of cold produced in the secondary or brine system. The results obtained by computing the cold produced by the brine measurement method should be only a little less than would be

DATA FOR TEST OF SINGLE-ACTING, 60-TON REFRIGERATION MACHINE

1.	Duration of test (hrs.)	12
2.	Average suction pressure (gage)	19
3.	Condenser pressure (gage)	154
4.	Rpm	125
5.	Temperature of condenser water, °F.	
6.	Outlet	73
7.	Inlet	60
8.	Difference—inlet and outlet	13
9.	Weight of cooling water used per hour (lbs.)	58,000
10.	Btu absorbed per hr. by cooling water	754,000
11.	Temperature of brine, °F.	
12.	Inlet	32
13.	Outlet	16
14.	Temperature difference	16
15.	Specific heat of brine	0.76
16.	Weight of brine circulated per hour (lbs.)	65,000
17.	Cold produced in Btu. per hour	790,400
18.	Tonnage capacity in 24 hrs	65.9
19.	Temperature of ammonia at compressor inlet, °F.	16
20.	Temperature of ammonia at compressor outlet	282
21.	Temperature of ammonia at condenser inlet, °F.	92
22.	Temperature of ammonia at condenser outlet, °F.	66
23.	Temperature of ammonia at expansion valve, °F.	69
24.	Temperature of ammonia leaving cooler, °F.	11
25.	Weight of ammonia circulated per hour (lbs.)	1,605
26.	Refrigerating effect (Btu per pound)	496
27.	Kwh. of current used per hour	111
28.	Kwh. used per ton of refrigeration per day	40.4
29.	Indicated horsepower of compressor	86

shown when the results are obtained by measuring the amount of ammonia circulated and temperature produced.

Where direct expansion is not used, the brine method of refrigeration produced can be substituted with close approximation for the ammonia measurement method. The results obtained by the brine measurement method should differ only in the amount of heat picked up by the brine from sources other than the ammonia coils. For positive check the ammonia heat balance method is most desirable.

HEAT BALANCE

The heat balance should show:

(1) Work of compressor.

(2) Heat lost by compressor-to-condenser piping and to jacket water.

(3) Heat lost to condenser.

(4) Heat gained—condenser to evaporator or refrigerator.

(5) Heat gained in evaporator or refrigerator.

(6) Heat gained—evaporator-to-compressor piping.

Step-by-step Solution for Heat Balance. (See Figure 10–2 for diagrammatic chart of total heat or enthalpy values.)

Work of Compression. By item 29 the indicated horsepower is 86.

One horse power equals 2545 Btu per hr.

Then the heat added by compression will be 2545 by 86, which equals 218,870 Btu.

Heat Lost in Compressor-to-condenser Piping and to Jacket Water. The ammonia leaves the compressor at a temperature of 282° F. at 154 lb. gage pressure. The enthalpy or total heat of one pound of ammonia as it leaves the compressor will be made up as follows:

Heat of liquid at 154 lb. gage pressure	138.7 Btu
Latent heat	492.8 Btu
Superheat	124.1 Btu
Total	755.6 Btu

When the ammonia enters the condenser it is at 92° F., according to the test data given. The enthalpy or total heat of one pound of ammonia at 154 lb. gage and at 92° F. is as follows:

Heat of liquid at 154 lb. gage	138.7 Btu
Latent heat	492.8 Btu
Superheat	4.3 Btu
Total	635.8 Btu

The heat lost per pound is the difference of the two superheat values, or 124.1 − 4.3, or 119.8 Btu.

The heat lost by 1605 lb. of ammonia circulated per hour will be 1605 × 119.8, or 192,279 Btu.

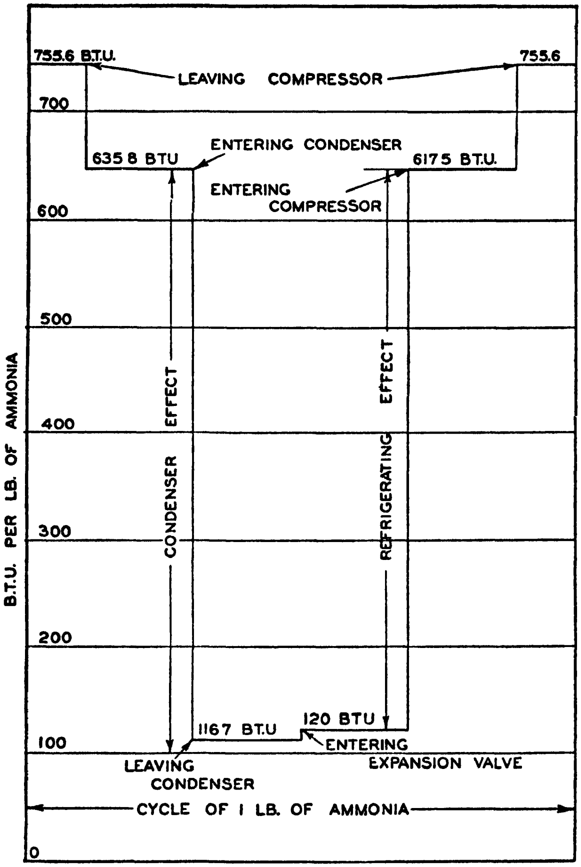

Fig. 10–2.

Heat Lost to Condenser. Temperature of gas entering condenser is 92° F.

Temperature of ammonia corresponding to pressure of 154 lb. is 85.8° F.

Superheat in degrees is 92 − 85.8, or 6.2°.

The total heat or enthalpy of one pound of ammonia gas entering condenser is 635.8 Btu, as outlined above.

The temperature of the ammonia at the condenser outlet is 66° F.

The total heat of ammonia liquid at 154 lb. gage and 66° F. is as follows:

Heat of liquid..	116.7 Btu
Latent heat. .	0 Btu
Superheat ..	0 Btu
Total	. 116.7 Btu per lb.

The heat lost in the condenser will be, then, for each pound of ammonia, 635.8 − 116.7, or 833,155 Btu.

Heat Gained—Condenser-to-evaporator.

Temperature of ammonia at inlet to evaporator .	69° F.
Temperature of ammonia at outlet of condenser..	66° F.
Difference	3° F. per lb.

Since the specific heat of liquid ammonia at this pressure is 1.12, the heat gain per pound of ammonia will be: 3 × 1.12 = 3.36 Btu. The heat gained by 1605 lb. of ammonia will be 1605 × 3.36 Btu. or 5400 Btu.

Heat Gained in Evaporator. The heat gained in the evaporator is equal to the enthalpy of the gas leaving the evaporator less the enthalpy of the ammonia entering the evaporator.

Temperature of liquid ammonia entering the evaporator	69 Btu
Heat of liquid entering evaporator is.	120 Btu

The enthalpy of the gas leaving the evaporator at 11° F. and 19 lb. gage is as follows:

Heat of liquid............ .	47.6 Btu
Latent heat of evaporation....	. 565.5 Btu
Superheat............... . .	4.4 Btu
Total per pound..........................	617.5 Btu

Heat gained per pound is 617.5 − 120, or 497.5 Btu.

Heat gained by 1605 lbs. in one hour is 1605 × 497.5 or 798,487 Btu.

Heat Gained in Evaporator-to-compressor Piping.

Total heat of gas leaving evaporator...	**617.5 Btu**
Total heat of gas entering compressor.....	**619 Btu**
Heat gained per pound of gas...................	**1.5 Btu**

Total heat gained is 1605 × 1.5, or 2407 Btu in one hour.

Calculations of Test.

No. 8 = No. 6 − No. 7: (73 − 60) = 13° F.
No. 10 = No. 8 × No. 9: (13 × 58,000) = 754,000.
No. 14 = No. 12 − No. 13: (32 − 16) = 16.
No. 17 = No. 14 × No. 15 × No. 16: (16 × 0.76 × 65,000) = 790,400 Btu.

$$\text{No. 18} = \frac{\text{No. 17} \times 24}{288{,}000} = \frac{790{,}400 \times 24}{288{,}000} = 65.9 \text{ tons.}$$

No. 26 = 617.5 − 120 = 497.5 Btu (from tables).

$$\text{No. 28} = \frac{\text{No. 27} \times 24}{\text{No. 18}} = \frac{111 \times 24}{65.9} = 40.4 \text{ kwh.}$$

The method of checking the computations of the heat gained in the evaporator by comparison with the "cold" produced in the evaporator is as follows:

By item 17, the cold produced in the evaporator is 790,400 Btu per hr. This is equivalent to 65.9 tons of refrigeration.

By computations the heat picked up by the ammonia in the evaporator was 798,487 Btu. This is equal to 66.5 tons of refrigeration.

The difference between the 66.5 tons and the 65.9 tons represents the refrigeration lost to radiation and heat loss from the evaporator walls and system.

Energy Balance

	Heat Gained	Heat Lost
Work of compression	218,870	
Radiation from compressor-to-condenser pipe line		192,279
Heat lost to condenser		833,155
Heat gained condenser-to-evaporator pipe line	5,400	
Heat gained in evaporator	798,487	
Heat gained evaporator-to-compressor pipe line	2,407	
Total	1,025,164	1,025,434

THE DETERMINATION OF OUTPUT OF THE AMMONIA COMPRESSOR BY THE INDICATOR

In testing a refrigeration plant, it is often inconvenient to make determinations of the compressor capacity by weighing ammonia or measuring it volumetrically. Although the measurement methods of weighing or measuring by graduated tank are the more desirable and accurate in determining compressor output, there are many times when an indicator analysis of the output is sufficiently accurate to give the information desired.

The Indicator. Before dependence can be placed upon the indicator it should be calibrated against a reliable steam gage. This is accomplished by mounting the indicator on a steam drum in which the pressure can be throttled. The indicator is mounted on this drum and placed under various steam pressures. At each pressure a horizontal line is drawn on the indicator card with the indicator pencil. By measurement of the height of these pressure lines above the atmospheric line, the accuracy of the instrument can be determined. After calibration, the ammonia indicator is mounted on the compressor and a typical card taken of the machine working under the load.

Indicator Diagram. A typical diagram obtained from an ammonia compressor is shown in Figure 10-3. The length of the diagram *A* corresponds to the stroke of the compressor to some reduced scale. The length *A* does not include the piston clearance, but represents only the moving stroke of the piston. The curved line *BC* is the typical compression line for ammonia. This line rises in pressure above the discharge pressure of the machine to a point sufficiently high to open the valve. The reasons why this pressure must exceed the discharge pressure are:

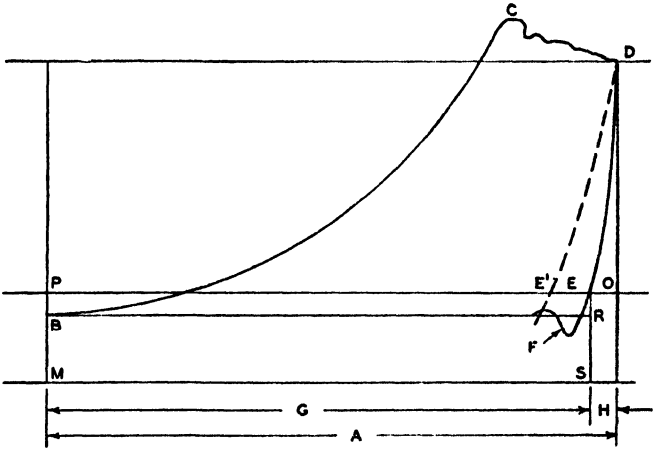

FIG. 10-3.

(1) The friction of the valve mechanism must be overcome in addition to the pressure of the gas on the opposite side.

(2) The lower side of the valve usually is slightly less in area than the top side, due to its conical design. This means that there are more square inches of opposing force on the upper side of the valve than there are square inches of lifting force on the lower side of the valve. This necessitates, therefore, greater lifting force per square inch on the lower side of the valve.

As can be noted on line *CD*, the pressure immediately drops as soon as the valve opens at point *C*. The valve closes at the end of the forward stroke, at which time the pressure equals the discharge pressure.

Depending upon the amount of clearance, a certain amount of ammonia will be left in the cylinder and as the piston starts on the back stroke the cylinder space back of the piston will be filled with this left-over ammonia. The greater the clearance, the more ammonia will be left in the cylinder back of the piston, and the longer period of time it will require for the pressure back of the piston to drop to the suction pressure of the system. This is shown on the drawing by the relative positions of *E* and *E'*. *E* represents a small clearance with little ammonia left in the cylinder and a rapid drop of the suction pressure. *E'* represents a large clearance with considerably more ammonia left in the cylinder and a slow drop of the suction pressure. As is indicated on the diagram, the pressure within the cylinder falls below the suction pressure of the system, and fills the space back of the piston with ammonia. Throughout the suction stroke, from *F* to *B*, the pressure will remain considerably below the system suction pressure.

As is represented on the diagram, the distance *H* is measured between the two vertical lines projected from *D* and *E* respectively. *E* is the point where the suction line of the indicator and the suction pressure line of the system cross.

Compressor Clearance. The clearance of the machine will be represented by *H* and the volumetric efficiency can be determined by analysis as shown by the rectangles in the accompanying illustration.

The rectangle *MNOP* is constructed equal to the length of the indicator diagram with the height equal to the distance from the absolute zero-pressure line to the suction-pressure line. A second rectangle is formed, *MSRB*, again using the absolute vacuum line for a base and a height equal to *MB* or the distance from absolute vacuum to suction-pressure line of indicator diagram.

The volumetric efficiency of the machine can now be computed by determining the areas of these two rectangles. The area of the smaller rectangle divided by the area of the larger rectangle will give the value of the volumetric efficiency; or:

$$\frac{\text{Area of } MBRS}{\text{Area of } MNOP} = \text{Volumetric efficiency.}$$

After determining the volumetric efficiency of the machine, the next procedure is that of determining the theoretical displacement on the basis of 100% volumetric efficiency. This will equal the volume of the cylinder multiplied by the number of strokes per minute. When this value is determined, the product of the true volumetric efficiency and the theoretical displacement per minute will equal the actual cubical displacement of the machine at the observed suction and discharge pressures.

Most handbooks on refrigeration give the actual displacement required per ton of refrigeration at different suction and discharge pressures. The computed actual displacement of the machine indicated divided by the tabulated displacement required per ton would give the tons of refrigeration per hour of the machine under test.

The errors that creep into such a test may easily total 6 to 8%. The errors due to indicator lost motion, indicator inertia and the indicator spring are usually appreciable. In addition to this, the available tables seldom show any correction to be made for superheat in the ammonia cycle, but under actual operation superheat affects the output of the machine very noticeably.

As an acceptance test, the indicator method should be used only when both buyer and purchaser agree to accept it as satisfactory with the full understanding that the results obtained are only approximate.

TESTING MECHANICAL CONDENSING UNITS

Circular No. 14 of the American Society of Refrigerating Engineers can be secured by addressing the Society at 40 West 40th Street, New York City. The circular gives the adopted "Standard Methods of Rating and Testing Mechanical Condensing Units." "Mechanical Condensing Units" are those larger than household but, for most applications, smaller than the independently assembled industrial plants. They are self-contained on one base. The remainder of this section are some extracts from Circular No. 14:

"Quantities Defined and Test Conditions.

(1) A Mechanical Condensing Unit is a specific refrigerating machine combination for a given refrigerant consisting of a motor-driven compressor for operation at a given speed, a condenser, a liquid receiver and the regularly furnished accessories.

(2) The Power Input Rating of an electrically driven mechanical condensing unit is its total power input in watts when the unit is operating under standard test conditions.

(3) The Capacity of a mechanical condensing unit is the refrigerating effect in Btu per hour produced by the change in total heat content between the liquid refrigerant, leaving the condensing unit per hour and the total heat content of the vapor refrigerant entering the condensing unit per hour under standard test conditions.

(4) Test Conditions. Capacity Rating of a mechanical condensing unit shall be expressed in Btu. per hour or in tons, each of 12.000 Btu. per hr., under conditions specified as follows:

   (a) Temperature of the ambient in degrees F.
   (b) Temperature of the saturated refrigerant vapor in degrees F.
   (c) Temperature of the refrigerant vapor entering the condensing unit in degrees F.
   (d) Temperature of the ingoing cooling water, if any, in degrees F.
   (e) Temperature of the outgoing cooling water, if any, in degrees F.
   (f) "Wet bulb" temperature of air entering evaporative condenser, if any, in degrees F.
   (g) "Dry bulb" temperature of air entering air-cooled condensers, if any, in degrees F

The A.S.R.E. Standard Capacity Rating of a mechanical condensing unit shall be measured under conditions defined as follows:

(1) The unit ratings shall be divided into standard groups based on saturated refrigerant vapor temperatures in the tabulation below.

TABLE 10–1. TEST CONDITIONS-CONDENSING UNITS

Group No.	Saturated Refrigerant Vapor, Temperatures, °F.	Water-cooled Condenser			Evaporatively Cooled Condenser			Air-cooled Condenser	
		Cooling Water, Temperature, °F.		Refrigerant Vapor Temperature Entering Condensing Unit, °F.	Air Entering Temperature, °F.		Refrigerant Vapor Temperature Entering Condensing Unit, °F.	Air Entering Temperature, Dry Bulb, °F.	Refrigerant Vapor Temperature Entering Condensing Unit, °F.
		In-going	Out-going		Dry Bulb	Wet Bulb			
I	Minus 10	75	85	65	90	75	65	90	80
II	Plus 5	75	90	65	90	75	65	90	80
III	Plus 20	75	90	65	90	75	65	90	80
IV	Plus 40	75	95	65	90	75	65	90	80
V	Minus 10	75	85	15	90	75	15	90	15
VI	Plus 5	75	90	30	90	75	30	90	30
VII	Plus 20	75	90	40	90	75	40	90	40
VIII	Plus 40	75	95	55	90	75	55	90	55

The temperature of the refrigerant vapor entering a condensing unit depends primarily on the arrangement of the refrigerant circuit, the size of the condensing unit and the characteristics of the refrigerant.

For groups Nos. I, II, III and IV, temperatures specified for the refrigerant vapor entering the condensing units are intended as a rating basis for condensing units which are usually applied with the refrigerant vapor entering the condensing unit at the specified temperatures.

For groups Nos. V, VI, VII, and VIII, temperatures specified for the refrigerant vapor entering the condensing unit are intended as a rating basis for condensing units which cannot usually be applied with the refrigerant vapor entering the condensing unit at the temperatures specified in Groups Nos. I, II, III and IV.

(2) The saturated refrigerant vapor temperature shall be determined by the suction pressure as measured at the suction inlet connection to the condensing unit.

(3) The standard ambient temperature for air-cooled, air-and-water-cooled or water-cooled condensing units shall be 90° dry bulb. The standard ambient temperature for condensing units equipped with evaporative condensers shall be 90° F. dry bulb and 75° F. wet bulb.

(4) The Performance Factor of a mechanical condensing unit is the ratio of its capacity to its energy input, expressed in Btu per watt and/or tons, each of 12,000 Btu per hr., per kw.

(5) The Cooling Water Consumption of a mechanical unit is the total number of gallons required per hour.

Methods for Testing. There shall be a primary test and a simultaneous confirming test. These two tests shall agree to within 3% but the former shall govern for rating purposes.

(1) Primary tests acceptable:
  (a) Brine tank calorimeter.
  (b) Concentric tube calorimeter.
  (c) Secondary refrigerant calorimeter.
  (d) Flooded system primary refrigerant calorimeter.
  (e) Dry system primary refrigerant calorimeter.

A condensing unit calorimeter is an apparatus for determining the refrigerating capacity of a condensing unit by measuring the heat input required to balance the refrigerating affect produced by the condensing unit. The various types listed depend upon the mechanical arrangements and type and condition of heat transfer medium.

(2) Confirming tests acceptable:
  (a) Liquid refrigerant quantity method.
  (b) Liquid refrigerant quantity meter and flow meter.
  (c) Condensing water method.

Methods 2(a) and 2(b) determine the refrigerating capacity by measuring either with measuring cylinders or meters the circulation of the refrigerant in a liquid state. The third method 2(c) determines the refrigerating effect produced by the condensing unit from the heat transferred to the condenser water.

Test Procedure.

(1) Instruments, whose types and accessories are given, shall be calibrated against secondary standards before and after each test.
  (a) Temperature measuring instruments.
    (1) Mercury-in-glass thermometers.
    (2) Thermocouples.
    (3) Electric resistance thermometers.
      (a) Accuracy
        (i) Brine or water in calorimeters ± 0.1° F.
        (ii) Water in condensing when data used in capacity calculations ± 0.1° F.
        (iii) All other temperatures ± 0.5° F.

- (b) Pressure measuring instruments.
    - (1) Mercury column.
    - (2) Bourdon tube gage.
        - (a) Accuracy
            - (i) Suction pressure, absolute, ± 1%.
            - (ii) Other pressures, absolute, ± 2%.
- (c) Electric measuring instruments.
    - (1) Indicating.
    - (2) Integrating.
        - (a) Accuracy
            - (i) Indicating within 0.5% of full scale reading.
            - (ii) Integrating within 1%.
- (d) Refrigerant flow measuring instruments.
    - (1) Liquid refrigerant quantity meter. (Volume)
    - (2) Liquid refrigerant flow meter. (Volume)
        - (a) Accuracy within ± %.
- (e) Brine or water flow measuring instruments.
    - (1) Liquid quantity meter, measuring either weight or volume.
    - (2) Liquid flow meter.
        - (a) Accuracy within ± 1%.
- (f) Speed measuring instruments.
    - (1) Revolution counter.
    - (2) Tachometer.
    - (3) Stroboscope.
    - (4) Oscillograph.
        - (a) Accuracy within ± 0.25%.
- (g) Time measurements with apparatus within accuracy of ± 0.1%.
- (h) Weight measurements with apparatus within accuracy of ± 0.2%.

(2) Tables of physical properties from the current issue of ASRE *Data Book.*

(3) Test Conditions.

- (a) Preparation
    - (1) Operated 72 hrs. before test started.
    - (2) Unit must be in a room where the temperature can be controlled.

- (3) No refrigerant vapor must leave the unit.
- (4) Correct oil and refrigerant charges placed in the proper locations and the refrigerant maintained at normal operating level in the liquid receiver.
- (5) The unit operated for at least 1½ hrs. and then shut down with the suction stop valve and the condensing unit liquid outlet valve closed. The temperature corresponding to the saturated state vapor pressure on the high pressure side of the condensing unit shall be within 2° F. of room temperature after the unit has stood idle in a constant temperature room for 12 hrs.
- (6) Mechanical checks made to insure refrigerating system gas tightness, proper belt tension, compressor valve tightness and condenser unit mounting comparable to service conditions.

(b) Operation and limits.

- (1) Regulate voltage at meter terminals to within ± 2% of meter rated voltage.
- (2) Adjust low pressure side to specified suction pressure at condensing unit ± 1% of absolute pressure.
- (3) Adjust the temperature of suction vapor at the condensing unit to 65° F. ± 5° F.
- (4) For water-cooled condensing units, adjust temperature of inlet water to 75° F. ± 0.5% F. and adjust the water rate to give the outlet temperature according to Group No. for test condition. The average ambient temperature shall be 90° F. ± 2° F. No abnormal air flow shall be created over the unit.
- (5) For air-cooled condensing units, the average temperature is to be that obtained from four thermometers properly placed and protected. The temperature of flow shall be 90° F. ± 1° F. No abnormal air flow to be created.
- (6) Operate until study temperatures and mechanical equilibrium are established.

Data to Be Recorded.

- (1) Pressure of refrigerant vapor entering the unit.
- (2) Temperature of refrigerant vapor entering the unit, measured at 24 in. from the compressor.

(3) Condenser pressure at inlet.
(4) Temperature of liquid refrigerant leaving the unit.
(5) Ambient temperature at unit.
(6) Temperature of cooling water entering the unit.
(7) Temperature of cooling water leaving the unit.
(8) Gallons of cooling water per hour.
(9) Pressure of cooling water entering the unit.
(10) Pressure of cooling water leaving the unit.
(11) Revolutions per minute of compressor.
(12) Revolutions per minute of motor.
(13) Watts input to condensing unit.
(14) Volts at motor terminals.
(15) Frequency at motor terminals.
(16) Barometric pressure.
(17) Wet bulb temperature.

Report of Test Includes.

(1) Test number.
(2) Date of test.
(3) Condensing unit manufacturer's name.
(4) Condensing unit model designation.
(5) Motor nameplate rating.
(6) Comparison test speed.
(7) Compressor displacement in cubic inches per revolution.
(8) Refrigerant.
(9) A.S.R.E. rating group number.
(10) Condensing unit capacity in Btu per hour or tons each of 12,000 Btu per hr.
(11) Motor input in water or kilowatts.
(12) Water consumption in gallons per hour.
(13) List of condensing unit accessories regularly furnished and in place during test."

SECTION XI

INSTRUMENTS AND CONTROLS

A refrigerating plant must be provided with sufficient instruments, if the operating engineer is to know how each part of the system is functioning. Without instruments, the engineer is forced to guess at the conditions inside any particular unit and cannot operate the system efficiently or locate trouble quickly. Instruments are costly and a high degree of skill is required to maintain and repair them; hence many plants are not provided with a sufficient number of instruments. Pressure gages are always supplied with each compressor or absorption unit, but frequently these indicate erroneously after some usage and give an entirely false picture of the true operating conditions. Thermometers are almost universally provided for refrigerated rooms, ice tanks or brine systems; however, few condensers are equipped with any means to determine the temperature of the entering and leaving streams of water or refrigerant.

An indicator card readily shows faulty valve action or piston leakage in a reciprocating compressor, yet very few engine rooms are provided with the instrument to take such a record of the cylinder conditions. Flow meters or flow indicators are particularly useful to show at a glance whether or not a particular piece of apparatus is operating satisfactorily.

In the cold storage of many foods, humidity control is equally as important as the maintenance of correct temperature. Two types of humidity meters are in use—namely, the wet- and dry-bulb thermometer and the type which utilizes the dimensional change of some hygroscopic substance to operate the indicating mechanism.

Pressure Gages. Pressure gages of the Bourdon dial type are almost universally used. In operation, these instruments are subjected to vibration transmitted through the piping and the pressure pulsations of reciprocating compressors, hence their accurate adjustment may be lost and erroneous pressures are indicated. For this reason a standard test gage should be provided, to be used only in calibrating gages which are in service. A mercury-filled manometer is sometimes employed to indicate the pressure in the low side of the refrigeration system. Its advantage is that a false indication is not possible unless oil or liquid collects in the tube

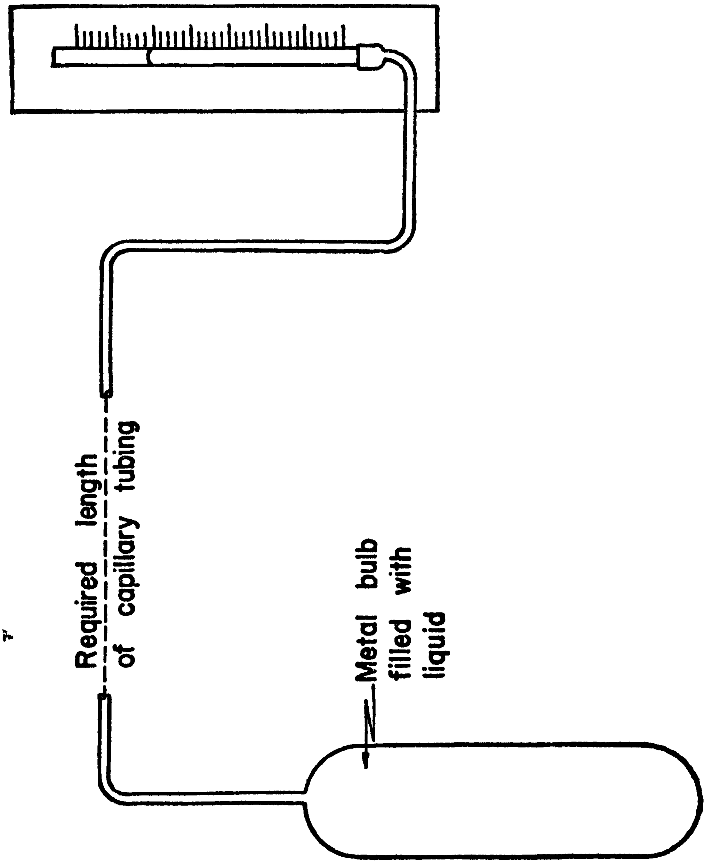
Required length of capillary tubing
Metal bulb filled with liquid

FIG. 11-1. Remote indicating thermometer.

above the mercury, but this condition is at once apparent and a correction is easily applied. A stop valve must be included in the manometer connection, which is closed when pressure beyond the range of the instrument may be developed.

Thermometers. Liquid-in-glass type thermometers are most frequently used in the refrigerating plant. The etched-stem type has graduations engraved directly upon the glass stem and consequently cannot get out of adjustment. Many plant thermometers have scales attached to a protective frame or tube which encloses the glass stem, but if the scale becomes loose, a serious error may be incurred. All liquid-in-glass thermometers are fragile and should be protected from shocks and vibration, although it is surprising how much abuse a well-installed instrument can take and still remain in serviceable condition. Accurate observation of the indication is difficult where the light is poor or when the glass stem is dirty, and frequently thermometers are located in inaccessible places.

To avoid these difficulties of observation and also to bring all indicating instruments into one group, where the conditions throughout the system may be determined at a glance, the remote indicating thermometer has been developed (see Figures 11–1 and 11–2). This consists of a fluid-filled metallic bulb located within the space where temperature is to be measured and connected to an indicating device by means of a capillary tube. One type of indicating device is a glass tube partially filled with colored liquid which changes level as the liquid in the metallic bulb expands or contracts under the influence of temperature changes. This is, in effect, an ordinary thermometer in which the ungraduated portion of the stem has been lengthened and made flexible. A second type employs a gas-filled bulb which is connected to a Bourdon pressure gage, graduated to indicate the temperature corresponding to the pressure created by heating the bulb. Still another type utilizes a dial gage, actuated by the pressure of vapor in a bulb which is partially filled with a suitable volatile liquid.

Liquid Level Gages. Gage glasses of standard type are quite satisfactory for indicating the level of liquids which are at or above room temperature. However, they are not suitable for indicating the liquid level in a refrigerant evaporator, since the tube soon becomes covered with frost and it is impossible to distinguish the top of the liquid column. To overcome this difficulty, an insulated gage glass has been devised which consists of two concentric glass tubes sealed together and having the annular space highly evacuated and silvered, except for longitudinal strips which are left clear to permit observation of the liquid column. This method of insulation retards heat flow to such an extent that the external tube does not become cold enough to collect frost. A makeshift liquid level gage, which is fairly successful, uses the formation of frost on the outside of a pipe which is connected to the evaporator in the same manner as a gage glass. The portion of the pipe which is below the liquid level is chilled by evaporation and collects a coating of frost from the moisture in the air, whereas the portion of the pipe above the liquid level is not chilled and consequently remains free from frost. The indications of this type of level gage are only approximate and response to a drop of the liquid level is very slow.

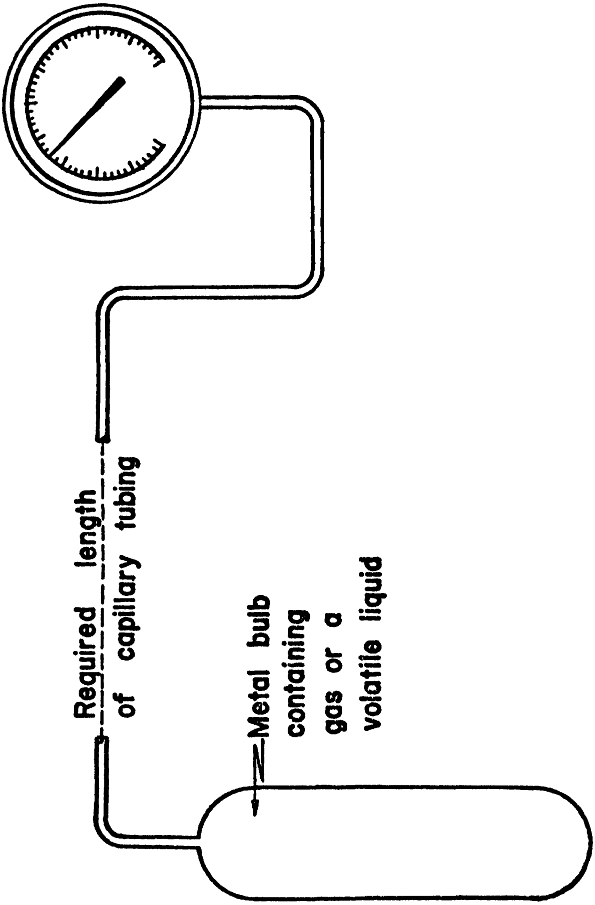
Required length of capillary tubing
Metal bulb containing gas or a volatile liquid

Fig. 11-2. Remote indicating thermometer.

Fluid-flow Meters and Indicators. Flow meters of the disc type, similar to the well-known water meter, are used to measure the flow of liquid refrigerants. For such service, special materials which are resistant to the liquid must be used and the parts must be sufficiently strong to resist working pressures. Orifice meters (see Figure 11–3) are satisfactory for the measurement of either liquid or gas flow and may be obtained in types which indicate the flow rate or record the total flow over a period of time. A special type of orifice meter consists of a vertically mounted tapered transparent tube through which the fluid to be metered flows in an upward direction. A specially formed plummet in the tube is forced upward until the pressure drop, through the variable orifice formed between the conical inside wall of the tube and the plummet, is balanced by the weight of the plummet. A scale

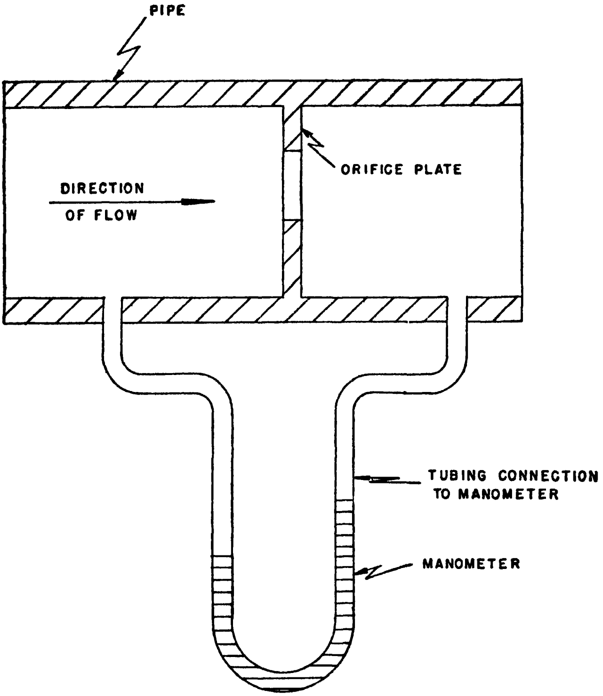

FIG. 11–3. Schematic diagram of indicating orifice meter.

beside the tube indicates the flow rate corresponding to various positions of the plummet (see Figure 11–4).

Flow indicators are very convenient in many locations in the refrigerating plant, particularly where the flow rate is quite small. One simple type is a cell provided with windows to observe the position of a pivoted vane which is deflected by the stream of moving fluid. A second type employs a propeller or wheel which is mounted in a transparent cell and is rotated by the fluid stream. The indication of either type is approximate, but they show at a glance any great deviation from normal operating conditions.

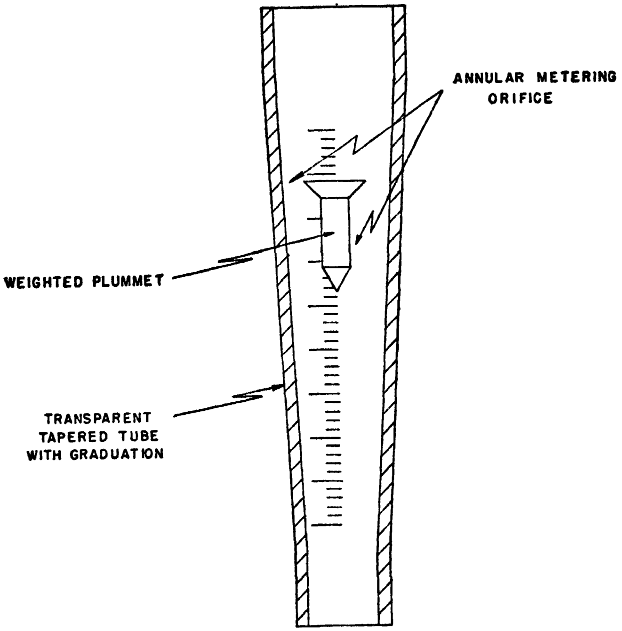

FIG. 11–4. Variable orifice meter.

Humidity Measuring Instrument. The "sling psychrometer" for measuring relative humidity of air comprises a pair of thermometers, one of which is provided with a loosely knit fabric cover upon the bulb, which is wetted with water before using. Both thermometers are mounted in a frame equipped with a pivoted handle so that they may be rapidly revolved or "slung" in the air. In air which is not saturated, the evaporation from the wet fabric cover causes the wet bulb thermometer to read a lower temperature than the instrument having the dry bulb. The indications of the two thermometers may be used to determine the relative humidity with the aid of a psychrometric chart. A variation of this device comprises wet- and dry-bulb thermometers mounted upon a stationary frame. To secure accurate results, the air should be blown over the thermometers with a velocity of approximately 1000 ft. per min., but for many applications the indication of the instrument in still air is sufficient.

A second type of psychrometer employs the change in dimensions of fibers or membranes which absorb water from moist air. One instrument consists of a band of approximately fifty human hairs, one end being fixed and the other end attached to an indicating pointer. In dry air, the hair loses moisture and shrinks, whereas in moist air the opposite effect takes place. Another type utilizes the twisting of a spiral element which is sensitive to humidity changes. These instruments must be calibrated at known air humidities which may be determined by the dew-point method or by means of the wet- and dry-bulb psychrometer. Corrections must be made for wide temperature variation, but over a limited range the relative humidity indication is approximately accurate.

AUTOMATIC CONTROLS

All controls of a refrigeration system regulate directly or indirectly the flow of fluids, which may be liquids, vapors or gases. Hence, the majority of controls are valves; though electrical switches are also employed to start and stop compressors and thus to indirectly regulate the flow of refrigerants.

Power elements for the automatic control of refrigeration machinery may be divided into three general types:

(1) Elements which respond to variations of liquid level.
(2) Types which are sensitive to temperature change.
(3) Types which are responsive to pressure variation.

Some of these may directly operate the control devices, such as valves or electrical switches, whereas others actuate pilots or relays to supply energy for the operation of the control devices. For the sake of simplicity and low initial cost, it is desirable to use a power element which will directly operate the valve or switch, but large control devices may require more force than is exerted by an element of economical size.

A float exemplifies the most widely employed power element which responds to variations of liquid level. The float may consist of a hollow metal vessel of sufficient strength to withstand the pressures which are encountered in operation or during idle periods and it may be counterbalanced by a weight or spring system. When large pressures may be attained, the hollow float may be replaced by a solid metal mass which is counterbalanced by an equal mass located above the highest liquid level. When the liquid is a conductor of electricity, its rise or fall may be employed to close or open a circuit between two stationary electrodes in the containing vessel.

Temperature sensitive elements depend upon the change of dimensions which occurs when some suitable material is heated or cooled. The bi-metallic element consists of a structure built of two metals having different coefficients of thermal expansion. A strip made by welding together two layers of dissimilar metal has the property of warping when the temperature is changed. By fixing one end of the strip, attaching an electrical contact point to the free end and providing a second fixed contact, the warping of the strip will open or close an auxiliary power circuit. Another type utilizes a triangle composed of three pivoted links, having two sides of one metal and the third side of another metal. When one link is fixed, any change in temperature causes a motion of the apex of the opposite angle, which may be used to operate control devices.

The thermal expansion of fluids may supply the energy to operate control devices. A simple form of thermally actuated electrical switch is a glass thermometer, having contact points inserted through the walls of the stem in such a manner that the circuit is closed when the mercury thread touches the upper contact. In another form, the expanding fluid is allowed to act against a flexible member, such as a diaphragm, a bellows or a Bourdon tube, and thus do mechanical work, which is transmitted to the control device. The force exerted by an expanding liquid is very large, but the degree of movement is small because of the low coefficient of thermal expansion which characterizes the liquid state. Gases possess a much larger coefficient of expansion, but the greatest change in volume occurs when a liquid passes to the vapor state.

This latter principle has been widely used in temperature sensitive power elements for automatic control devices. The increase in pressure and volume, which occurs when a liquid is vaporized by heating, acts against a flexible member to compress a spring and adjust the position of the control device. A reduction in temperature causes the vapor to condense with a decrease in pressure and volume which allows the spring to expand and move the control device in the opposite direction. This type of element transmits sufficient energy to operate many controls directly, but large valves are frequently operated by auxiliary power which in turn is controlled by the element.

Pressure sensitive power elements consist of a cylinder and piston or a flexible member, such as a diaphragm, a bellows or a Bourdon tube against which the pressure may act and cause movement of the control device. A spring system or weight is provided, which absorbs part of the energy when an increase of pressure occurs, and returns the control device when the pressure decreases.

Liquid Refrigerant Control. The expansion valve, which separates the high side and the low side of the system and meters liquid refrigerant to the evaporator, may be considered as the most important control in the system. Manually operated needle valves are the simplest form and are satisfactory when the load is constant and operator is vigilant. The frequent adjustment of the expansion valve, which is necessary with rapidly fluctuating loads, has caused the virtual abandonment of the hand-operated valve and the adoption of automatic types.

The low-side float control is used with flooded evaporators to maintain the liquid at a predetermined level. Refrigerant is supplied only when vaporization is occurring and the accurate metering effect allows any number of evaporators to be used in a system. It comprises a valve which is operated by means of a float, located either inside the evaporator or in a float chamber which is connected in such a manner that the same liquid level is maintained in the chamber and the evaporator. In the smaller sizes, a needle valve alone is employed, but larger sizes include a calibrated orifice in series with the valve. Division of the pressure drop into two stages reduces erosion of the needle and valve seat, which may be very rapid when throttling is accomplished in a single stage. The orifice is replaceable and its bore should be of a caliber which will pass only the quantity of liquid refrigerant required for the maximum cooling load. Some low-side float controls are equipped with "snap action" valves, which are either wide open or completely closed, thus concentrating the throttling effect at the replaceable orifice and eliminating erosion of the valve parts. While this arrangement greatly prolongs the life of the valve, it may introduce an irregular action of the evaporator because of the fluctuation of the liquid level. A low-side float switch may be used to control a magnetically operated liquid valve which provides the "snap action."

In a system which contains only a single evaporator, the high side float gives effective control of the liquid supply for flooded operation. Unlike the low side float, which accurately meters liquid as vaporization occurs, the high side float control cannot be used to supply multiple evaporators with liquid. It is essentially a float trap which drains liquid from the condenser to the evaporator but prevents the flow of uncondensed refrigerant vapor. The amount of refrigerant in the system must be carefully adjusted to secure satisfactory operation since with this type of control all liquid is stored in the evaporator. Too much refrigerant will cause carry over of liquid from the evaporator to the compressor while too little will not permit the system to work at full capacity.

The constant pressure expansion valve comprises a throttle valve which is controlled by a diaphragm or a bellows actuated by the pressure in the evaporator. It can be used only to control dry expansion coils under fairly constant load conditions. If a heavy load is suddenly applied, the evaporator pressure rises and the constant pressure valve cuts off the supply of liquid just when it is most needed. Conversely, when the load is very light the evaporator pressure falls, but the flow of liquid is increased when it should be decreased.

Thermostatic expansion valves employ a temperature sensitive power element to regulate the position of the valve which admits liquid refrigerant to the evaporator. One type, which is made by a number of manufacturers, is operated by means of a metallic bellows or a diaphragm which is located in the low-pressure portion of the valve body and is thus subjected on one side to the pressure prevailing in the evaporator (see Figure 11–5). An adjustable spring adds its force to the action of the evaporator pressure and tends to close the valve. The opposite side of the bellows or diaphragm is enclosed in a fluid tight housing which is connected by means of a capillary tube with a bulb containing a charge of volatile liquid. This "feeler" bulb is mounted on the evaporator suction line in a manner assuring good thermal contact and thus its temperature follows closely that of the suction vapor. When the temperature of the suction line exceeds a predetermined value, the pressure exerted by the volatile liquid in the bulb moves the bellows or diaphragm against the combined effects of evaporator pressure and spring, to open the valve more widely. As more liquid is admitted to the evaporator, the temperature of the suction vapor is decreased and the valve opening is decreased in proportion to the temperature drop. Thus, by merely adjusting the spring tension, the valve may be set to maintain a constant suction superheat which is largely independent of the evaporator pressure. When used with coil evaporators of great length, in which considerable frictional pressure drop occurs, it is necessary to use an "equalizer" connection between the suction line and that portion of the valve body which houses the bellows or diaphragm. This connection insures that the internal pressure acting to close the valve will be the true suction pressure at the point where the "feeler" bulb is placed.

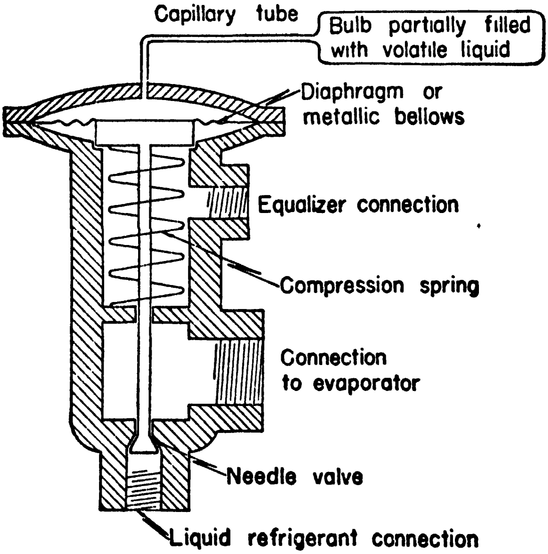
Capillary tube
Bulb partially filled with volatile liquid
Diaphragm or metallic bellows
Equalizer connection
Compression spring
Connection to evaporator
Needle valve
Liquid refrigerant connection

FIG. 11-5. Thermostatic expansion valve.

Close temperature control of a refrigerated space may be maintained by employing dry evaporator coils which are fed with liquid refrigerant by a thermostatic expansion valve in series with a shut-off valve operated by a room thermostat. Thus, liquid may enter the coil only when refrigeration is required and the thermostatic expansion valve insures that the evaporator will operate at maximum efficiency without danger of liquid carry over to the compressor.

A device which functions as the expansion valve of a refrigerating machine is the capillary tube used in many domestic refrigerators and small hermetically sealed units. It reduces the pressure between the condenser and evaporator by means of fluid friction in a section of tubing having a very small bore. The satisfactory operation of this device depends upon a nice balance between compressor capacity, tube dimensions and the amount of refrigerant in the system. It is apparent that the refrigerator temperature may be controlled only by "on and off" operation of the compressor, since the volume of liquid refrigerant flowing through the tube is dependent only on pressure drop. When the compressor is idle, pressure throughout the system is equalized and thus the starting load consists only of friction and acceleration work. As the machine runs, gas is forced into the condenser faster than it passes through the capillary, thus the pressure rises until condensation takes place and liquid passes to the evaporator, which is now at low pressure. Advantages of the capillary are its extreme simplicity and the fact that there is no moving part to get out of order, while the equalization of pressure during the off period permits the use of low starting torque motors. Strict control must be exercised in assembly to avoid the presence of dirt particles which might choke the tube.

One method of controlling refrigerator temperature is to hold the evaporator at a given pressure and thus maintain the vaporizing liquid refrigerant at a constant temperature. If the suction pressure is lower than the desired evaporator pressure, an automatic throttle valve in the vapor line is a convenient solution of this problem. One simple and reliable type of power element used to control such a valve consists of a metallic bellows or diaphragm, which is subjected to evaporator pressure on one side and to the force exerted by an adjustable spring on the opposite side. In operation, the bellows or diaphragm maintains a position, at which the pressure force balances the spring force. A small increase of pressure compresses the spring and opens the valve sufficiently to prevent further increase, while a slight decrease allows the spring to expand and move the valve toward the closed position.

The power element may be connected directly to the mechanism of a small valve, but a large unit requires more force than is exerted by a bellows or diaphragm of convenient size. In the larger valve, the mechanism is operated by a piston which utilizes the pressure drop between the evaporator and the suction line. A small pilot valve, which is operated by a bellows or diaphragm, is used to control the movement of the piston.

The constant pressure valve maintains satisfactory temperature control when the refrigerator load is constant, but with a variable load other methods of control must be employed. A thermostatically operated valve may be used to throttle the flow of vapor from the evaporator and adjust the evaporation rate in accordance with the imposed load. In this case the temperature of the evaporator is not held constant but decreases in proportion to the demand for refrigeration. For this service the valve may be operated by a temperature sensitive power element consisting of a metallic bellows or diaphragm, a spring and a small reservoir of volatile liquid which is maintained at refrigerator temperature. Atmospheric pressure and the spring act upon one side of the bellows or the diaphragm and the vapor pressure of the volatile liquid acts upon the opposite. A slight increase of refrigerator temperature warms the reservoir and increases the vapor pressure of the volatile liquid. This unbalance compresses the spring and moves the valve to a position which permits more rapid flow of vapor and consequently an increased evaporation rate to prevent further temperature rise.

Evaporator pressure control is a simple method to control a refrigerator when the compressor must run continuously to operate other cooling equipment or to maintain an unvarying temperature level. However, it is not recommended where the power rates require maximum operating efficiency, since any throttling process causes losses of energy and reduces the effective capacity of the machine. A variation of temperature is usually permissible in the operation of refrigerated devices and this allows control between specified limits by means of "on and off" operation of the compressor. A thermal element in the refrigerated space starts the compressor at some predetermined maximum temperature and stops it when the desired minimum is reached. Thus the machine runs at approximately full design capacity and its maximum efficiency is secured.

This method is particularly well adapted to the control of small electrically driven units. In certain designs, the evaporator and its refrigerant contents serve as part of the thermal element which starts and stops the compressor. When the machine stops, the evaporator gains heat and within a short time the internal pressure rises to that of saturated vapor at the prevailing refrigerator temperature. Any increase of the refrigerator temperature causes a corresponding rise in vapor pressure, which is transmitted through the suction line and closes a switch. As the compressor operates the evaporator temperature drops to some predetermined value at which the corresponding reduction of vapor pressure allows a spring to open the switch.

SECTION XII

ATMOSPHERIC WATER COOLING

The cooling and recirculating of condenser water is necessary in a large number of refrigeration and air conditioning plants. In many regions the ground-water supply is not sufficient to meet all industrial demands, and even should it be possible to pump the water from a ground supply source for less cost than it could be recirculated to a pond, a spray pond or a cooling tower, the urgent need to conserve the ground-water supply to meet all domestic and industrial needs makes it imperative in these areas that no water be wasted.

Ground-water temperatures are a function of the mean annual temperature of the location from which they originate. The approximate year-round temperatures of water from springs or wells for the region around Minneapolis is 44–45° F.; Omaha, 52–54° F.; Kansas City, 55–57° F.; Oklahoma City, 62–65° F.; Dallas, 66–68° F.; and Austin, 70–72° F.

The corresponding normal mean annual air temperatures published by the U. S. Weather Bureau for these same locations are: Minneapolis, 43° F.; Omaha, 50° F.; Kansas City, 55° F.; Oklahoma City, 64° F.; Dallas, 65° F.; and Austin, 68° F.

On the other hand the reported maximum water-main temperatures show very little relationship to ground-water temperatures but are more nearly a reflection of the design of the municipal water supply systems.

Of the six cities considered above, the lowest maximum summer water-main temperature is in Minneapolis, with 80° F., and the highest is Austin, with 88° F. Thus, while the ground-water supplies vary 26° F., the water-main maximums vary only 8° F. Since in most cities the maximum refrigeration demands occur at the same period that the water-main temperatures are a maximum, the effectiveness of cooling ponds, spray ponds or cooling towers in solving the cooling water problem must be given serious consideration.

Methods of Cooling to Be Used. In commercial practice, several choices for cooling water for refrigeration condensers are available. The principal commercial methods are:

(1) Cooling or lake ponds.
(2) Spray ponds.
(3) Cooling towers:
    (a) Spray.
    (b) Natural draft.
    (c) Mechanical draft.

Heat That Must Be Dissipated. In previous sections of this handbook it was stated that for low-suction pressures such as are employed in ice-making, approximately 1⅓ times as much heat must be carried away by the condenser as is added in the cooler. Since the extraction of heat at the rate of 200 Btu per min. is equal to one ton of refrigeration, then the dissipation at the condenser of 1⅓ this amount of heat would be equal to 266 Btu per min. or 16,000 Btu per hr. For low-suction pressures, the dissipation of 260 to 280 Btu per min. may be necessary at the condenser. For high-suction pressures, such as are used in air conditioning, 225–240 Btu per min. would be ample for each ton of refrigeration produced.

For engines and turbines the heat that must be dissipated by the condenser will be approximately 1000 Btu for each pound of steam used by the prime mover. Paradoxical as it may seem, condensing turbines operated in connection with spray ponds and cooling towers usually require less water than noncondensing units. The steam consumption of noncondensing turbines is so much higher than for condensing units that the extra steam required to operate the turbine is much greater than the drift and evaporation loss encountered when recirculating the turbine condensing water.

When a Diesel engine is the prime mover, it is necessary to allow from 3000 to 4000 Btu per hp. for the cooling water load of the cooling pond or tower.

POND-COOLING

Where land is inexpensive, rainfall very seasonal, humidity low, wind velocities high and available well-water supplies either highly incrustating or unduly expensive, the cooling pond offers a most satisfactory solution for condenser water supply. Every refrigeration plant owner requiring condensing water for the prime movers, or for refrigerant condensation, should investigate the economics of pond-cooling in determining his ultimate cooling water supply source.

The cooling effect of a surface pond depends upon the relative humidity, the wind velocity, the radiant heat of the sun, the radiation to the ground and the temperature difference between the pond water surface and the wet-bulb temperature immediately above the water.

Interpolation of field results for the Southwest shows that for air temperatures between 60° F. and 90° F., the heat dissipated by ponds whose surfaces are 20° above that of the surrounding air is from 4 to 6 Btu per sq. ft. per hr. per degree temperature difference between water surface and air. On this basis 150 to 225 sq. ft. of pond surface per ton of refrigeration would supply the cooling capacity for an ice plant with the water coming from the condensers at 100° F. and entering the condenser at 82° F.

Cooling ponds should be located where excessive flooding is not anticipated. Many owners of power plants in the West and Southwest have found cooling ponds more economical than either spray ponds or cooling towers. For further discussion on average pond performances, see "Pond Cooling by Surface Evaporation" by D. O. Lima in the March, 1935, issue of *Power*.

Where rains are very seasonal, it is desirable to make the dam large enough to collect sufficient water to carry over the drouth periods. The *run-off water* is more desirable than most well and spring water from the standpoint of scaling. The larger the dam capacity, the more uniform the operating temperature conditions can be maintained, but the cooling effect of the pond is largely confined to the surface evaporation; thus, the minimum requirements for ample pond surface for cooling the required demands of the plant must be provided.

The wet-bulb temperature of the air is one of the controlling factors in pond evaporation. The pond surface can be cooled to nearly the wet-bulb temperature of the air but never below it and never quite equal to it.

In discharging the water into the pond, the warm water should be spread out over the surface of the pond. If the layer of the warm water coming from the condensers is delivered to the pond surface, the maximum temperature difference between the pond and the wet-bulb temperature of the air can be maintained with a resultant maximum evaporation. As the warm water is cooled by the evaporation of part of the water from the surface, it will gravitate to the bottom. Thus, the warm water will be maintained on the surface and the cold water will be on the bottom of the pond.

Formulas for Capacities of Cooling Ponds. Box gives the formula for the rate of pond evaporation in still air as:

$$E = \frac{(243 + 3.7t)(P_s - P)}{7000},$$

in which

E = evaporation in pounds per square foot per hour.
t = temperature of the water surface, ° F.
P_s = vapor pressure in inches of mercury at temperature of water surface.
P = vapor pressure at wet-bulb temperature of air in inches mercury.

Carrier gives the equation:

$$Q = 0.093r\left(1 + \frac{v}{230}\right)(P_s - P),$$

where

Q = Btu liberated per hour per square foot of pond surface.
v = the velocity of air in feet per minute over the water surface.
r = latent heat of vaporization at the temperature of the water in Btu per pound.

An *empirical* formula that will give values corresponding to experimental data secured in commercial ponds for temperatures between 70° F. and 110° F. is:

$$Q = 250(P_s - P),$$

where

P_s = vapor pressure in pounds per square inch at the temperature of water on pond surface.
P = vapor pressure in pounds per square inch of wet-bulb temperature of air.

Example. Find the size of pond necessary to supply cooling water for 40 tons of refrigeration under normal operating conditions with water coming from the condenser at 102° F., this water to be discharged onto the surface of the cooling pond. The surrounding air shows a dry-bulb temperature of 90° F. and a wet-bulb temperature of 77° F. The water is to be cooled to 82° F.

Solution. One ton of refrigeration equals 12,000 Btu per hr. Since the condenser load is normally 1⅓ times the refrigeration load, it would require 1⅓ × 12,000 or 16,000 Btu per hr. condenser water cooling.

For 40 tons of refrigeration, this would require 40 × 16,000 or 640,000 Btu per hr. to be dissipated in the cooling pond.

Use formula

$$Q = 250(P_s - P)$$

where Q is the quantity of heat dissipated per square foot of pond surface per hour, P_s is the vapor pressure per pound given in steam tables for the temperature of the pond surface, P is the pressure corresponding to the wet-bulb temperature of the surrounding air.

If the water is discharged to the pond surface at 102° F. and leaves the pond base at 82° F., it is a safe assumption that the surface will maintain an average temperature of 96° F.

$$P_s \text{ for } 96° \text{ F.} = 0.8403 \text{ lbs. per sq. in.}$$

$$P_s \text{ for } 77° \text{ F.} = 0.4590 \text{ lbs. per sq. in.}$$

Then $Q = 250(0.8403 - 0.4590) = 97.8$ Btu liberated per square foot of pond surface per hour.

To liberate 640,000 Btu per hr. will require a pond surface

$$\frac{640{,}000}{97.8} = 6540 \text{ Sq. ft.}$$

A pond 66 by 100 ft. would be required.

SPRAY PONDS

Spray pond-cooling makes possible the dissipation of a large quantity of heat in a relatively small pond. In its simplest form it consists of a water distribution system to well-placed spray nozzle heads. In these heads the water is broken up into small droplets and projected upward, after which it falls to the level of the collecting tray or basin.

Since the spray heads project the water upward in proportion to the water pressure at the nozzle, it is desirable to design the distribution mains so that the pressure is approximately the same on each nozzle. Likewise it is desirable to have the heads uniform in size and design, since each type of head functions best under the conditions for which it has been designed. For any given grouping of nozzles of one type the pressure difference between any two nozzles should not exceed ½ to 1 lb. per sq. in. The usual design is based on an assumed wind velocity of 5 mph. and a spray nozzle pressure of 5 to 12 lbs. per sq. in.

The heat-dissipating capacity of a spray pond for each pound of water sprayed can be increased by (1) decreasing the "spot" concentration of sprayed water by using many small nozzles in preference to a few large units; (2) raising the elevation of the nozzles to give a longer period of contact with the air in falling to the pond level; (3) spreading out the nozzles used to expose the water to incoming air that is not already saturated with moisture; and (4) increasing the pressure on the nozzles to give a greater atomization of the water. However, it must be considered that increased atomization of the water also increases the driftage loss from the pond.

The main objection to a spray pond as compared to a cooling pond in many areas is the drift of the water or mist with the wind. Simultaneously with this nuisance of drift to the side of the pond in the direction of the wind there is some probability of the picking up of lint and delivery of the same to the pond by the wind as it comes through the pond louvres from the opposite side. This is especially noticeable in textile mill and cotton gin areas. Under such conditions the accumulated lint often causes considerable inconvenience by collecting in the circulating pumps, necessitating frequent repairs.

Spray nozzles are usually placed from 3 to 6 ft. above the water level and must be supplied by the circulating pumps with 4 to 10 lbs. pressure at the spray distribution main. In present-day plants, low-priced nozzles of very simple design are most common. These vary in capacity from 10 to 50 gal. per min. They are spaced on rows of pipe from 16 to 20 ft. apart at 8 to 16 ft. intervals. Each square foot of pond area capacity is from 1 to 5 gal. per min.

Drift will vary with prevailing wind velocities and operating pressures. It is usually necessary to provide at least 20 to 25 feet between the edge of the spray pond and the first row of nozzles to prevent water blowing over the edge in the case of high winds; when the spacing is not possible, a louvred fence from 10 to 12 feet high is recommended. If wood is permissible under the fire regulations of the location, cypress or California Redwood is recommended. When fireproof materials must be used, galvanized louvres are usually employed.

Spray ponds are often placed on the flat roof of ice or cold-storage plants, over a heavy composition roof. If copper flashings have been used in the roof construction some care must be exercised if ammonia condensers are receiving the sprayed water. In case of ammonia leakage in the condensers, the copper would corrode quickly from the ammonia-contaminated spray water.

The loss of water from evaporation and drift in most areas does not exceed 3%, although in some areas of prevailing high winds the loss by driftage for any one day may reach 5 or 6%. Designers of spray ponds should analyze their location very carefully to determine whether the pond as designed is likely to provoke nuisance lawsuits. Typical complaints are: (1) railroad right-of-way superintendents object to a spray pond next to the right of way, because a high wind spreads the water to the embankments and softens them; (2) hotel guests in adjacent buildings complain that the hissing sound of the spray prevents them from sleeping; (3) passing pedestrians in congested areas charge that a suit, a coat or a hat has been spotted and ruined by cooling-pond driftage.

Good design calls for the long axis to be normal to the prevailing winds. Since the heaviest ice-plant loads occur in the summer time, ice-plant spray cooling ponds should be placed with their long axis normal to the prevailing summer winds.

Periodic treatment of spray ponds with either potassium permanganate or chlorine to prevent the growth of green algae is recommended. Concentrations of 5 to 6 parts per million of chlorine are usually sufficient to control the algae growth. If potassium permanganate is used, a concentration sufficient to hold a 12-minute pink discoloration immediately after addition of the solution should be ample. Fortnightly treatments are usually sufficient. Algae growth is increased by sunlight; thus an area of high sunlight intensity produces more algae tendencies.

The depth of the spray pond basin has little effect upon the pond-cooling capacity. The basin should be designed to give the most satisfactory storage for the operating conditions of the plant concerned.

The actual cooling of a spray pond is limited by the wet-bulb temperature of the air. Wet-bulb temperatures vary much less than dry-bulb temperatures. Observations on some summer periods in Austin, Texas, show entire months in which the maximum wet-bulb temperature did not exceed 78° F. and the minimum was not below 69° F. In this same period the daily dry-bulb temperature rose to between 90° F. and 102° F. and dropped nightly to within 3 or 4° of the wet-bulb temperature.

With a wet-bulb temperature of 75° F., the water temperature leaving a carefully designed spray pond should be from 78° F. to

81° F., and an 80° F. wet bulb should give a water temperature of 83° F. to 85° F. For further data see "Atmospheric Cooling Equipment for Condenser Water" by F. D. Mosher, *Heating and Ventilating Magazine*, May, 1937.

COOLING TOWERS

When space does not permit the installation of cooling or spray ponds, recourse is taken to extending the cooling job to higher levels. Many different classifications might be used in defining the different types.

Spray Towers. The spray tower design moves the spray nozzle up to a higher level than is used in the spray pond. The water is sprayed downward or upward inside a fully louvred enclosure, then falls to the basin below. The long path of travel of the sprayed water permits cooling very nearly to the wet-bulb temperature of the air. When the spray is upward, the spray deck is usually located just above the middle of the tower. When the spray is downward the deck is located at the top.

In common practice the width and height are approximately equal and the unit capacity is from 0.5 to 1.5 gal. per min. for each square foot of tower area.

Natural-draft Towers. The natural-draft deck type tower, sometimes called the atmospheric tower, is built up with several decks placed at regular levels and may extend up to a height of 60 to 80 ft. in widths up to 40 ft. Each platform or deck is designed to be a supporting member of the tower and also to serve as "packing" or retarding and diffusing part of the total structure.

The water to be cooled is spread out over the upper deck by sprays, troughs or splash heads, then flows downward over the several retarding deck structures to the basin below. The circulating air travels across the tower between the several decks and evaporates and cools the falling droplets of water.

The structure must be rugged to withstand windstorms, although normally it is designed to do its cooling job at wind velocities of 3 to 5 mph. The free flow of air from all directions should be investigated before building the tower, since the tower's effectiveness is largely determined by natural air circulation; if this is impeded, the capacity of the tower is greatly reduced. A well-built deck tower should have a capacity to thoroughly cool from 2 to 5 gal. of water for each square foot of area per minute.

Mechanical-draft Towers. Mechanical-draft towers may be of either the forced draft or the induced draft type and may be either wood packed or spray filled.

The mechanical-draft tower is especially desirable where it is necessary to install the tower inside a building or in an area where natural draft is not uniformly dependable. The louvres are replaced by watertight walls, and the discharge outlet from the draft fans is so arranged that it will not contribute as a nuisance into either the building in which it is housed or to adjacent buildings.

For design purposes a fan wind velocity of 400 to 800 ft. per min. is allowable and the drift loss will approach that of the commercial spray pond. About 2 to 6 gal. per min. of water per square foot of tower area can be handled in a typical design. It will require from 100 to 160 cu. ft. of circulated air per gallon of water circulated.

The heat balance of cooling towers has been written by Barnard, Ellenwood and Hirshfeld as:

$$W_1h_1 - [W_1 - W_a(W_b' - W_a')h_2] + W_a(h_a' - h_b') = 0$$

where

W_1 = pounds of water entering the tower per minute.
W_a = pounds of dry air passing through tower per minute.
W_b' = pounds of water vapor mixed with each pound of discharged dry air.
W_a' = pounds of water vapor mixed with each pound of entering dry air.
h_1 = Btu per pound in entering water.
h_2 = Btu per pound in exit water.
h_a' = Btu per pound of air vapor mixture entering the tower.
h_b' = Btu per pound of air vapor mixture leaving the tower.

From this equation:

$$W_a = \frac{W_1(h_1 - h_2)}{h_b' - h_a' - (W_b' - W_a')h_2}$$

CONCENTRATION OF IMPURITIES IN COOLING SYSTEM

For every 1000 lbs. of water cooled 1° F., approximately one pound is lost by evaporation. If make-up water is added from a source that contains impurities, it does not require a long period to produce a residual circulating water supply that is highly concentrated with impurities. By the evaporation process, pure water is given up, but the continued supply of make-up water to replace this evaporation has brought in the continuous supply of impurities.

Probably 1 to 3% of the water in spray ponds, spray towers and deck towers will be lost to driftage, but this lost water will contain approximately the same solids as prevail in the basin or pond. What has been lost by driftage is replaced by water of a similar impurity content.

To prevent a high concentration of impurities, the make-up water should be treated chemically before it is added to the system.

RELATION OF CONDENSER SIZE TO COOLING EQUIPMENT

There is a definite relation between the amount of water pumped through the condenser, the temperature of the refrigerant coming off the condenser, and the condenser design. Some managers purchase condensers that are too small. Usually it is necessary to pump large quantities of water through these condensers. Since the path is short for the water, it does not pick up very much heat per pound.

If condensers of longer water path are used, the water can pick up more heat per pound circulated and there will be a greater difference between the temperature of the water coming off the condenser and the wet-bulb temperature of the air.

SECTION XIII

FILTERS AND WATER SOFTENERS

Water is treated: (1) to remove solid matter; (2) to change the chemical nature; (3) to clarify it; (4) to make it safe to drink. In some cases it is necessary to give water treatment for all of these, but usually only part of the factors enter into the problem.

Solid matter is usually removed either by means of filters or by settling tanks. The simplest method is, of course, that of the settling tank. The limitation for such a method is largely determined by the tank size. It is not possible to clarify water by a straight settling process in less than several hours. To reduce the amount of the equipment necessary or to secure greater capacity for the same equipment, the filter bed method is commonly used. In this method the water is required to pass through a bed of sand, quartz or similar material, where the solid matter is extracted. The requirement of such a filter is that the bed of good sharp sand or quartz permit the water to percolate through the filter without the bed being packed to an unnecessary degree.

Such a filtering process can usually be made continuous. The capacity for the same size equipment is far greater than is possible in the simple settling tank method.

Although a process of filtering will readily remove the principal solids present, there is often a very finely divided material that is not filtered by any such means. To remove matter, it is usually necessary to use some coagulant. To explain what the term coagulant means, consider the application of a coagulant in the making of coffee. The effect of adding the white of an egg to the boiling coffee is that the coffee liquor, which a moment previous to the adding of the egg white was full of grounds, becomes remarkably clear. The grounds have gathered about the egg white in a coagulated mass leaving the coffee liquor clear for pouring.

For the water filtering process, especially for the extremely finely divided particles, this same principle is used. Since egg white is entirely too expensive, other materials equally effective are secured at much less cost. For instance, alum is used successfully. Its introduction into the water brings about a reaction with other chemical salts and forms on the filter bed with particles so minute that even the most finely divided materials in the solution are trapped in their path and thus separated. It is apparent that with such a process it is not always necessary to add continuously the alum solution, as a "floc" once formed will have some permanence. The alum used may be the common lump alum or some of its class relatives.

Occasionally water is found which is too soft to permit the alum to successfully do its job of coagulating. In such a case, a small amount of soda ash is usually added to make the water sufficiently alkaline to coagulate regularly.

For boiler use it is usually necessary to treat water to change its chemical nature. There are two kinds of water hardness—one is called temporary and the other permanent hardness. The combined hardness may be referred to as the total hardness.

Temporary hardness is due to the presence of carbonates of calcium, magnesium and iron. These are the same carbonates usually found in the feed-water heater when it is cleaned out. They precipitate at feed-water temperature of 212° F. or less.

Permanent hardness is due to the presence of the sulphates of calcium, magnesium and iron and the chlorides of the same group. A temperature of over 300° F. is required to precipitate these impurities.

To soften water, both the temporary hardness and the permanent hardness must be overcome. For temporary hardness it is treated with lime either in the form of milk of lime or in the form of lime water. The lime combines with the carbonates and forms a precipitate that can be readily filtered out.

For permanent hardness the water is treated with soda ash or, in other words, with carbonate of soda. This in turn forms an insoluble precipitate with the sulphates, chlorides and nitrates and these can be filtered out.

The equipment necessary for this complete process thus calls for a treating tank in which the lime and the soda ash can act on the water; then there must be a suitable filter to separate the deposit after it has precipitated.

When this process is operated with cold water it is very slow and requires a large storage space. This equipment can be greatly reduced in size by using exhaust steam for heating the water and speeding up the process.

Commercially the industry uses the hot and cold processes of treatment. Some are available that work on an intermittent schedule. The former are usually the most satisfactory.

WATER PROBLEMS IN ICE MAKING

The problems that may confront the ice manufacturer from unsatisfactory water are:

(1) Formation of brittle ice.
(2) Development of cracks in ice block.
(3) White surface or shell around ice block.
(4) Concentration of impurities producing opaque ice at core.
(5) Cores of disagreeable odor and taste.
(6) Discolored cores at center of ice block.

Brittle ice and cracked ice usually can be traced to the same causes. It is difficult to put down a covering statement that will explain all cracked or brittle ice situations. A wide difference in the temperature of the brine and the ice cake is often the cause for unusual strains within the ice block with a resultant cracking. This situation can sometimes be relieved by raising the brine temperature above 12° F., but this cuts down the capacity of the plant accordingly. Excess of bicarbonates in the can water evidently introduces greater tendencies to ice cracking and several manufacturers have experienced excellent results in reducing the cracking by neutralizing the bicarbonate condition of the water.

Warm dipwater should be avoided in handling ice that has brittle characteristics. With ice that is unusually suceptible to cracking after it has been removed from the tank, a liberal tempering time should be given the ice so that the internal strains will be relieved by the slow warming up of the entire block.

White surfaced ice may be charged to either excessive salts in the water or poor agitation of the water or both. If the raw water can of ice had no agitation the entire block would be white ice. If there is inadequate agitation the ice that is nearest the can surface freezes so quickly in relation to the rate of agitation that it freezes white. The inner ice of the freezing block congeals more slowly and receives a greater agitation by virtue of the decreased section of unfrozen water in the can clear. The resultant block comes out of the can with relatively clear ice in the interior section but with a white shell.

The concentration of impurities at the center or a disagreeable odor and taste of the center ice can be avoided by pulling generous cores. If the cores are discolored either chemical treatment or filtering is recommended if the pulling of a generous core does not solve the difficulty.

LIME SOFTENING AND FILTERING

A lime softening system is made up of (1) lime feeder and proportioner, (2) mixer, (3) settling and clarifying tanks and (4) filter.

The bicarbonates of calcium and magnesium and carbonate of iron respond to the lime process of softening. The added lime water reacts with the carbonic acid to cause the bicarbonates to precipitate. Any concentration of calcium and magnesium carbonates can be present for the lime treatment for this reaction to give the desired results. The lime treatment will remove the hardness to approximately 2½ grains per gal. Lime treatment is not necessary if the combined calcium and magnesium hardness is less than 4 grains per gal., but it is advisable to treat water between 4 and 2 grains of combined bicarbonate of calcium and magnesium with alum to change these carbonates over to sulphates. It will result in reduced cracking of the ice and clearer ice.

After treatment with lime, the treated water is passed to the filters where most of the newly formed insoluble salts will be separated. The filtered water will make a satisfactory clear ice if the original assumption that the raw water was primarily a carbonate water was correct.

If only calcium, sodium and magnesium sulphates, and chlorides and sodium carbonate are present in a total hardness of less than 10 grains per gal., a clear ice can be produced without any treatment. Brine temperatures as low as 8 or 10° F. should be possible, without excessive cracking or white cores when using the normal amount of agitation of the can water. Beyond 10 grains of the combined sulphates and chlorides, more care of agitation will be necessary, and with considerable care merchantable ice should be possible up to 20 grains of hardness.

Soda ash treatment with lime will successfully remove the heavy concentrations of the sulphate and chlorides. This method is most satisfactory for boiler waters but is losing favor with ice manufacturers for water for making ice. The principal criticism against the soda ash treatment is the corrosive nature of caustic soda, especially on the galvanized coating of the ice cans.

TABLE 13-1. REAGENTS REQUIRED IN LIME AND SODA PROCESS FOR TREATING 1000 GALLONS OF WATER PER GRAIN PER GALLON OF CONTAINED IMPURITIES

Impurity	Pounds of Lime Required	Pounds of Soda Ash Required
Sulphuric acid	0.109	0.1627
Free carbon dioxide	0.2425	None
Calcium carbonate	0.1073	None
Calcium sulphate	None	0.1172
Calcium chloride	None	0.1433
Calcium nitrate	None	0.1028
Magnesium carbonate	0.2536	None
Magnesium sulphate	0.0889	0.1331
Magnesium chloride	0.1122	0.1680
Magnesium nitrate	0.075	0.1410
Sodium carbonate	0.0983	None
Aluminum sulphate	None	0.1400
Iron sulphate	None	0.1047
Sodium bicarbonate	0.1255	None
Iron and aluminum oxides	0.1912	None

ZEOLITE WATER SOFTENERS

Another softening process that has been going on through the ages is that of the natural hydrated aluminum silicates combining with other alkaline salts. These are known as zeolites. Zeolites readily exchange a part of their chemical composition with other salts. The element which makes zeolite most effective is sodium. The sodium is the active water softening agent. In the discussion of the calcium and magnesium salts, the carbonates of these elements formed temporary hard water, whereas the sulphates and chlorides formed the so-called permanent hard water. It is a substitution by the zeolites of sodium for calcium and magnesium that gives the soft water.

The chemical reaction is for instance:

Calcium bicarbonate + sodium zeolite =

Calcium zeolite + sodium bicarbonate.

As remarkable as the change seems, a still greater commercially important change is possible when the zeolites build up during idle hours. By saturating the calcium zeolite with common salt or sodium chloride, it is possible to get back the original sodium zeolite and a solution of calcium chloride, which is washed away with clear water. In actual process work, natural zeolite is not used.

Some manufacturers are using a mine material which is refined; others are producing a synthetic or manufactured zeolite.

The great advantage of the zeolite process is the possibility of approaching very closely to complete softening. For certain classes of work, this is not absolutely essential. Thus, in the operation of boilers the lime soda process is entirely satisfactory, and the added cost of the zeolite softener is often not justified for straight power plant requirements.

The zeolite process for boilers must be watched very closely if a large amount of carbonates are present. This is on account of the carbonates necessarily requiring a heavy sodium reaction and the excess of sodium in the water may then produce a foaming action in the boiler. In such cases it is usually advisable, if the zeolite process is already installed, to give the water a prior lime treatment to prevent the over accumulation of sodium salts. For ice making, the zeolite process has its limitations since there is a concentration of sodium salts within the water. When this concentration becomes too high, the resultant ice is not satisfactory.

Hydrogen Zeolite Water Softening

An improved zeolite that promises extensive application in ice making is sold under the trade name of Zeo-Karb. It is different from normal zeolites in that it is nonsiliceous and can be regenerated either by acid or salt.

When operated with acid, it exchanges hydrogen ions for sodium, calcium and magnesium ions within the water. The carbonates and bicarbonates are converted to carbonic acid and pass off from the solution by aeration.

When operated with salt the new zeolite functions like a normal zeolite and is designated as Zeo-Karb Na. When operated with acid the process is designated Zeo-Karb H.

Hydrogen zeolite has the great advantage to ice makers of removing all bicarbonates from solution. Likewise it removes the sodium, magnesium, calcium, iron, aluminum and manganese in the effluent water. Regeneration of hydrogen zeolite is accomplished by sulphuric acid used in a way similar to the regeneration with sodium chloride of the ordinary zeolite system.

The processed water may be used for boilers, for condenser cooling and for ice making.

WATER SOFTENING BY SYNTHETIC RESINS

Since 1935 considerable experimental work has been done in using synthetic resins for water treatment. Several types of synthetic resins have been used with success in removing both the carbonates and the metal bases from the water under treatment.

O. K. Smith,* reporting to the American Gas Association, states: "Perhaps one of the greatest improvements in the physical characteristics of these exchange materials over some of the former synthetic silicious zeolites are their increased capacities and durability. Smaller equipment and less floor space for the same capacity is not only an economic factor but quite often an advantage in installing the equipment."

Some of these synthetic resins are appearing on the market under the name of Amberlites. Although very new, they open up another process by which the impurities of the water can be completely removed from the water. They should find a very useful place in the making of ice.

COMPARATIVE HARDNESS FACTORS

Since certain compounds give relative hardness greater than certain other compounds, it is necessary to refer all to one standard compound. The standard compound used is calcium carbonate.

To put other impurities on the same basis as calcium carbonate ($CaCO_3$), multiply by the following factors:

	Multiply by
Calcium bicarbonate, $Ca(HCO_3)_2$	0.617
Calcium sulphate, $CaSO_4$	0.735
Calcium chloride, $CaCl_2$	0.901
Calcium oxide, CaO	1.790
Calcium nitrate, $Ca(NO_3)_2$	0.610
Magnesium bicarbonate, $Mg(HCO_3)_2$	0.684
Magnesium carbonate, $MgCO_3$	1.19
Magnesium chloride, $MgCl_2$	1.05
Magnesium nitrate, $Mg(NO_3)_2$	0.675
Magnesium oxide, MgO	2.48
Magnesium sulphate, $MgSO_4$	0.833

TO MAKE A HARDNESS TEST BY STANDARD SOAP SOLUTION

To determine the grains per gallon of total hardness in terms of calcium carbonate, a sample of 58.3 cc. of the water will be used.

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* Smith, O. K., "Water Purification by the New Ion-Exchange Method," *American Gas Association Proceedings*, 1943, pp. 308–314.

To determine the parts per million of total hardness in terms of calcium carbonate, a sample of 100 cc. of the water should be used.

This discussion will assume the determination is to be made in grains per gallon. The 58.3 cc. of water should be clear. If the sample is not clear, it should be filtered.

To neutralize sample, add 2 drops of methyl orange indicator, then add $N/50$ sulphuric acid from a burette until the yellow of the sample just starts to deepen to an orange throughout the solution.

Pour this neutralized water sample into a narrow neck test bottle and add standard soap solution by one-half of a cubic centimeter at a time, then shake vigorously after each addition of the soap solution. This procedure is continued until a soap lather is formed on the surface of the sample that lasts for at least 2 min. after shaking.

Caution must be exercised that a "ghost point," or false end point, is not mistaken for the true end point of the test. A true end point lather can be distinguished from a "ghost point" lather by the persistance of the soap solution to stick to the sides of the bottle when it is the true end point whereas a "ghost" end point is made up of small bubbles and stays on the water surface only.

The number of cubic centimeters of standard soap solution used minus one-half of a cubic centimeter equals the total hardness in grains per gallon in terms of calcium carbonate. The subtracted one-half of a cubic centimeter is termed the lather factor. It is the amount of standard soap solution required to make a lather with distilled water.

The number of cubic centimeters of N/50 sulphuric acid that was used to neutralize the sample above equals the total alkalinity in grains per gallon. If the alkalinity exceeds the total hardness by the soap test, it indicates all sodium carbonate. Excess sodium carbonate is not objectionable in boiler waters but is corrosive of the zinc coating on ice cans.

THE PHENOLPHTHALEIN AND METHYL ORANGE TESTS FOR BICARBONATE, CARBONATE AND HYDROXIDE ALKALINITY

This is often called the P and M test for alkalinity.

A clear sample 58.3 cc of water under test and at room temperature is poured into a large-mouthed beaker.

Two drops of phenolphthalein are added to the water sample. This gives it a pink color. This is now titrated from the N/50 sulphuric acid burette drop by drop until the pink color has just disappeared. The amount of sulphuric acid used is recorded as "P."

Now add 2 drops of methyl orange indicator and titrate with N/50 sulphuric acid until the sample changes from yellow to orange. The amount of sulphuric acid used is recorded as "M."

From these P and M tests the following deductions can be made:

If P = zero, the alkalinity is present as bicarbonates only.

If P = M/2, carbonates only are present.

If P = less than M/2, carbonates and bicarbonates are present.

If P = more than M/2, carbonates and hydroxides are present.

If P = M, only hydroxides are present.

In the lime treatment of water for ice making the presence of hydroxides shows excess of lime used. The hydroxides in grains per gallon can be approximated by the formula $(8P - 4M)/5$, where P and M are in cubic centimeters.

TABLE 13–2. DATA ON COMPARATIVE VALUES OF WATER HARDNESS

Quality of water.	Very good	Good	Fair	Bad	Very bad
Grains per U. S. gal. . .	8 –	15 –	20 –	30 –	30 +
Parts per million. .	135 *	257 *	350 *	500 *	500 +

* Or less.
+ Over
– Under.

CONVERSION FACTORS FOR WATER TREATING

One degree of hardness = 1 grain $CaCO_3$ per U. S. gallon.
1 ppm = 0.0583 grains per U. S. gallon.
1 lb. = 7000 grains = 453.6 grams.
One gram = 15.43 grains.
One U. S. gallon at 62° F. = 8.34 lbs. = 58,349 grains = 3781 grams.
One liter of water at 62° F. = 2.2 lbs. = 15,415 grains.
One grain per gallon = 17.15 ppm of water.
One grain per gallon U. S. = 1.2 grains per British Imp. gallon.
One grain per gallon U. S. = 1.71 French Degrees of Hardness.
One grain per gallon U. S. = 0.958 German Degrees of Hardness.

Engineers' Check List of Water-treating Equipment Inspection *

Item No.		*Checked By*	*Date Checked*
(1)	Remove heads from sand and gravel filters and check to see that filter bed is not channeled		
(2)	If channeling is evident, remove sand and thoroughly wash. It may be necessary to remove and wash gravel also		
(3)	Check to see that filters have proper filter bed with reference to depth and grade of sand		
(4)	Check chemical mixer bearing, chains, sprockets, etc. Order necessary repairs promptly		
(5)	Check chemical solution dip cups, outlet box and drain		
(6)	Check raw water control and float box		
(7)	Check chemical mixing tank for sludge accumulation. Tanks should be emptied and cleaned out once each year		
(8)	Check water analysis and treatment by qualified chemist. When private source of water is used, bacteriological analysis is imperative		
(9)	Keep shaking flasks, burettes, and testing cabinet clean and orderly. Remember this is your gage for making a food product		
(10)	Keep supply of soap solution, acid solution, P and M Indicators in tightly corked bottles at all times.		
(11)	Keep lime, soda ash, aluminum sulphate, and alum in well-covered and air-tight containers. This is very necessary precaution, particularly for lime.		
(12)	Check water treating before recharging lime or chemical tanks. Keep record of tests and treatment. There are many variables that require this precaution to produce a uniform quality of clear ice		
(13)	Check backwashing of filters by schedule. Do not use too high water pressure but just enough to float the sand bed		
(14)	Check water treating equipment. It is the heart of the ice plant if crystal clear ice is required		
(15)	Check good housekeeping in all the plant, and particularly in water treating equipment		
(16)	Check condition of I beam or other supports for chemical mixer tank		

* Check list compiled by R. A. O'Neil. Published by permission of Southwestern Ice Manufacturers Association.

SECTION XIV

ICE AND ICE MAKING

Physical Constants of Ice

Latent heat of fusion, Btu	143.4
Density of ice at 32° F.	0.91676
Specific heat of ice at 32° F.	0.504
Specific heat of ice at 0° F.	0.475
Specific heat of ice at −40° F.	0.431
Coefficient of expansion	0.00016
Weight of one cubic foot of ice, lbs.	57.3
Theoretical latent heat of sublimation at 32° F., Btu	1216.8

Forms of Ice

For refrigeration, five forms of ice are generally recognized. They are (1) natural ice, (2) can ice, (3) plate ice, (4) cube or mold ice, and (5) machine-formed ice.

Natural Ice. Natural ice has been used for refrigeration since the dawn of history. The Greeks stored quantities of ice from the mountain areas in caves for summer use. Nero established extensive ice houses for royal use. By 1700 A.D. western Europe had set up a considerable commercial trade in ice.

By the beginning of the nineteenth century, the New England states were shipping ice into Charleston and other southern ports. A few years later ice was exported to England and to India from Massachusetts.

In the process of freezing water, impurities become a part of the ice mass only when they are trapped between the forming ice crystals. Ice crystals themselves are formed of water less the silt and foreign matter. Thus, the freezing process becomes an auto-purification procedure even on silt-laden and contaminated streams and lakes. On open streams, nature purifies water by crystallization and rejects the foreign matter to the water below. Epidemics traceable to natural ice are very rare.

Can Ice. By far the greater portion of ice frozen in American ice plants is made in standard cans. It is so much more convenient to handle the large commercial supplies in block form that it has become the most popular with ice men.

Standard Sizes of Can. While not all cans are made standard, through the several associated societies interested in ice production, the following dimensions have been accepted as standard for the industry.

Table 14–1. Dimension of Standard Sizes of Ice Cans No. 16 Gage Metal

Nominal Weight of Block of Ice	Top Inside Dimensions of Can	Bottom Dimensions of Can	Inside Length of Can
50	8" x 8"	7½" x 7½"	31"
50	6" x 10"	5½" x 9½"	31"
100	8" x 16"	7¼" x 15¼"	31"
200	11½" x 22½"	10½" x 21½"	31"
300	11½" x 22½"	10½" x 21½"	44"
* 400	11½" x 22½"	10½" x 21½"	57"

* 400 pound can has a No. 14 bottom.

Virtually all of the early ice made was a distilled water or boiled water product. The distilling or boiling removed the air from the water and gave a relatively clear ice as a competitive product with the clear ice of the northern lakes.

Later experiments revealed that agitated water would give as good results, and mechanical agitators were introduced into the can to produce the desired clear ice from tap or unboiled water.

Mechanical agitation was found to be cumbersome and inconvenient. Air agitation was substituted so successfully that, today, practically every ice plant installed is a fresh-water plant equipped to make clear ice by air agitation, or white ice by no agitation whatever.

Table 14–2. Air for Agitation of Cans

Cubic Feet per Can per Hour	Size of Can in Pounds
15	50
20	100
25	200
30	300
35	400

Comparison of White and Clear Ice. Various traditions exist comparing white ice and clear ice. The clearness of the ice has but little relationship to its hygienic properties, and good white ice is equal in every way, except color, to clear ice. The cooling qualities of a pound of white ice are the same as those of a pound of clear ice.

Pulling Cores of Block or Can Ice. One of the earliest discoveries in the production of can ice was that most of the impurities contained in the can of water being frozen collect in the center of the can. The physical explanation of this is that the impurities contained in the water freeze at a lower temperature than the water itself and, thus, will be found concentrated in the part being frozen last.

This often produced a discolored or a distasteful ice at the center of the ice block. Water treated in municipal water plants with chlorine and chloride of lime, when used for ice making, often gave an ice core that tasted strongly of chlorine. Similar effects were noticed where excess iron or other chemicals were present in the water.

Core pulling has become almost a universal practice in eliminating this difficulty. When the outer shell of the ice block has frozen the core is pumped out and replaced with fresh or distilled water. Distilled water is preferable for filling cores since it permits freezing to the center as a *clear* ice. Air agitation is usually somewhat difficult when the core has about closed up. This necessitates freezing a thin center section of the block without agitation,which, with raw water, gives a white center. If the core is filled with distilled water, this is eliminated.

Water Supply. Probably the safest ice made is raw water ice, which is made from the city water supplies of American cities. The exacting requirements on the water supply of most municipal health departments guarantee a very high degree of safety in the use of city water.

Boiled or distilled water of many plants is far inferior to the average municipal supply. Sufficient care to guarantee safe water is often neglected in handling the distilled or boiled water after its boiling or condensing period.

Only positively hygienic water should be permitted to enter the ice can. The public has been trained to place unlimited confidence in the purity of ice. This trust must be upheld by vigilance of both the water supply and the frequent examination of those handling the cans and the ice.

If the water supply is furnished from reboilers or condensers, the precaution of filtering it through sand and charcoal and sponge filters is often advisable.

Rotten Ice. Rotten ice is the name usually applied to block ice that has not been completely frozen, thus leaving an open core. This ice melts rapidly because the ice next to this core is just at the freezing point, and the extra area exposed offers immediate chance of melting.

Cracked Can Ice. The complete prevention of the cracking of ice is the unsolved problem in many plants. The principal variables that evidently affect the ice are:

(1) Temperature of freezing.
(2) Condition of the can.
(3) Design of the can.
(4) Impurities of the water.
(5) Rate of pulling ice.
(6) Rate of dipping.
(7) Temperature of the dip tank.
(8) Uniformity of regulation of expansion valves.
(9) Circulation of brine.
(10) Design of evaporator system.

Temperature of Freezing. For most waters, the low safe temperature of the brine tank is 12° F. This will vary with the other conditions involved.

Condition of Cans. Due either to handling or to defective manufacture, many cans are bulged. The rate of freezing of a block of ice is inversely proportional to the square of the thickness of the block. If the cans are not uniformly tapered, the thin sections will freeze up before the thicker sections with a resultant strain in the colder, thinner sections. The ice will usually crack at these thin sections.

Design of Can. Closely related to the condition of the can is the can design. Cans that are grooved often give the can sufficient relief and rigidity to eliminate much of the cracking trouble.

Impurities of Water. In general, distilled water gives less trouble from cracking than raw water. Water taken from two different supplies but otherwise frozen under identical conditions often displays much different cracking tendencies. Water softening often reduces the cracking tendencies. In some sections it is common practice to add 2 ounces of alum to each 300-lb. can of water to reduce the cracking.

Those who are troubled with cracking, due to the nature of the water usually find it necessary to try out several treatments for definite results. That impurities have a very marked effect is generally recognized, but there is no definite solution to the difficulty.

Rate of Pulling Ice. Ice should be pulled while there is still a small unfrozen cup at the top of the block. The expansion of water in forming ice is approximately one-twelfth of its volume. This tends to push out in all directions. The can being practically rigid, the volume change takes place on the core or water side, thus pushing the water upward and producing a block of increased length. After solidifying at 32° F., the formed ice starts to drop to a temperature equal to that of the brine. Ice once formed contracts in volume for every degree it cools below 32° F.

There is going on in the block, then, a contraction at the outer sections at the same time that there is going on a very decided expansion at the freezing surface. So long as this freezing surface is kept open to permit some strain relief, cracking is not as probable; but, as soon as the block is completely frozen, the pressure strains become excessive, and since no relief is possible the ice cracks at the strain points.

The rate of pulling should be such, then, that no can is permitted to hold over or freeze up in the tank. There will be an increased production of ice with a decreased amount of cracking if this practice is adopted.

Rate of Dipping. The tendency to increase production by dipping rapidly sometimes creates excessive ice cracking.

Temperature of the Dip Tank. The temperature of the dip tank is closely related to the rate of dipping. Two general methods of procedure are available for good results. Either use a cold dip tank that does not permit any excessive strains in the block or use hot water and dip so quickly that the strains set up in the block are only surface strains that never have the opportunity to penetrate into the body of the block.

The cold dip tank can be adopted where the ice pullers are careless, since, with cold water, the time element is not of great importance in determining how much cracking will be produced. The hot dip is quick but must be used with certain precaution of the duration of the dip.

Uniformity of Regulation. Sudden changes in temperature in the freezing can will increase the strains in the ice. When the expansion valve is carelessly operated sudden changes of temperature will result in cracked ice.

Circulation of the Brine and the Evaporator Design. Just as the careless regulation of the expansion valve will cause unequal strains in the ice block, so will the uneven distribution of brine circulation and ammonia flow effect the temperatures in the various parts of the block with resultant ice-cracking strains. Systems so designed that the upper end of the block closes up before portions of the lower part are frozen will inevitably produce a high percentage of cracked ice.

Rating of Ice-making Plants. During the early period of the refrigeration industry, most refrigeration plants were rated on the basis of *tons* of *refrigeration* produced in twenty-four hours. This method was, technically speaking, correct. The *ice-making* capacity depends on several factors and is not a stable basis on which to rate machines, however. The rating of machines on the refrigeration tonnage basis has gradually given way to the rating of the machine on the ice-making basis.

This change has come about to convenience the man who cannot interpret technical data. To the layman, a ton of refrigeration was some unknown and almost mythical value, but a ton of ice was a very real and known thing that had a definite commercial value.

The heat that must be removed to make a ton of ice will depend upon:

(1) Heat removed to cool water to 32° F.

(2) Latent heat of fusion.

(3) Heat removed to cool the ice below 32° F.

(4) Heat that must be removed to make up for heat received by radiation.

A ton of refrigeration has been previously defined as the removal of 288,000 Btu, or the equivalent of the latent heat of fusion of one pound of water multiplied by 2000.

It is evident by comparing what is required to make a ton of ice with that required to produce a ton of refrigeration that these values will always differ by the amount equal to the sum total of items 1, 3, and 4 as listed above. In other words, the heat that must be removed to make a ton of ice will exceed the amount of heat that must be removed to produce a ton of refrigeration by the sum of the (a) heat removed to cool the water to 32° F., (b) heat removed to cool the ice below 32° F., and (c) the heat that must be removed to make up for the radiation losses.

Problem 1. Water is available at 80° F.; the average temperature of the blocks of ice coming from the evaporator is 22° F. The summertime losses due to radiation were 25%. Compare the *ice-making* capacity of the plant under these conditions with its *tons-of-refrigeration* capacity.
Solution.

Heat removed to cool one pound of water to 32° F. = (80 − 32) × 1	48	Btu
Latent heat of fusion of water	144	Btu
Heat removed to cool ice to 22° F. with specific heat of ice at .5 = (32 − 22) × .5	5	Btu
Total heat entering each pound of ice	197	Btu
Heat removed to make up for radiation will be 25% of 197	49¼	
Total refrigeration per pound	246¼	Btu

For one ton of *ice making* under these conditions, it will require 2000 × 246¼ or 492,500 Btu to be removed.

Since one ton of refrigeration is 288,000 Btu under the conditions outlined it will require $\frac{492,500}{288,000}$ or 1.71 tons of refrigeration to produce one ton of ice.

Problem 2. Under winter conditions the above plant has available water at 36° F., and the radiation losses are reduced to 8%. How will the ice-making and refrigeration tonnage compare?
Solution.

Heat removed to cool one pound of water to 32° F. = (36 − 32) × 1	4	Btu
Latent heat of fusion of water	144	Btu
Heat removed to cool ice to 22° F. from 32° F. with specific heat of ice .5 = (32 − 22) × .5	5	Btu
Total heat removed to produce each pound of ice	153	Btu
Heat removed to make up for radiation = .08 × 153	12¼	Btu
Total refrigeration per pound of ice frozen	165¼	Btu

Then for 1 ton of ice it will require 2000 × 165¼ or 330,500 Btu.

Comparing this with one ton of refrigeration at 288,000 Btu the relationship is $\frac{330,500}{288,000}$ or 1.147 tons of refrigeration to make 1 ton of ice.

Comparative Value of Ton of Refrigeration and Ton of Ice Making. Early practice among refrigeration engineers provided for heavy radiation losses, and it was commonly expressed that 2 tons of refrigeration were equal to one ton of ice making. With the improved development, it is common practice today to use the value 1.6 tons of refrigeration equal to one ton of ice making. This is based on 70° F. can water and an ice temperature of 16° F.

Cans Required per Ton of Capacity. The number of cans used per ton depends upon the freezing time necessary to produce a can of ice. This freezing time, in turn, depends upon the temperature of the can water, velocity of brine circulation and the practice followed in removing cans from the evaporator.

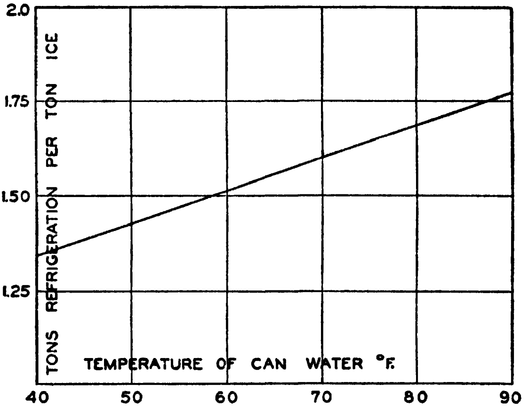

FIG. 14–1. Tons of refrigeration per ton ice making at different can water temperatures.

With precooled can water, rapid circulation, and an average brine temperature of 12° F. the average freezing time for a 300-lb. block of ice is about 36 to 40 hrs. The can requirement for such a plant would average about 12 per ton of ice produced. To provide for forced holdovers, it is sometimes advisable to increase this number to 15 cans to avoid delays.

Plate Ice. Plate ice was the form in which ice was introduced in the early history of ice manufacturing. The making of ice by the plate method has continued to a small degree up to the present date.

Fundamentally, plate ice is the ice frozen in sections approximately 10 by 14 ft. by 12 or 15 in. then later cut to size for the market.

Plate ice making requires heavy equipment for handling and considerable labor for cutting. Its principal advantage is that it eliminates the investment in a large number of cans.

Cube Ice. Cube ice has come into very common use due to the convenience of the cubes in fountain and table service. Its manufacture involves a high handling cost per ton of ice produced. This increases the sales price to prohibitive levels in many areas.

Sizing of Crushed Can Ice. In competition with cube ice the crushing and sizing of can ice has become an extensive commercial enterprise. Ice may be graded to sizes most suitable to the community to be served. An active agency in a large city can usually find a sale for all sizes of ice from the fine snow form to the larger egg lump. Many customers prefer the ice from the ice can to that coming from their refrigerator ice-making compartment since it is not as likely to carry over odors to the drinking water or ices from which the cubes are made.

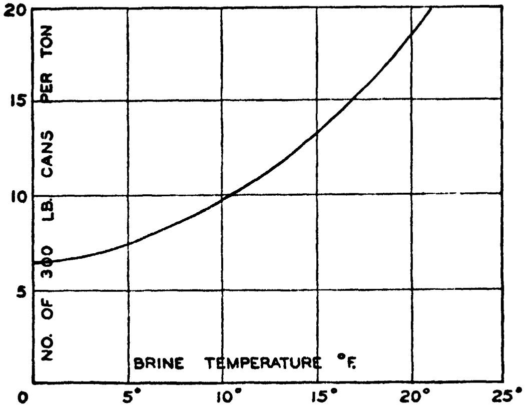

FIG. 14–2. 300 pound can requirements at different brine temperatures.

The extension of the crushed-and-sized ice business has been so great that the machine-made forms of flake and tube ice have found a very ready market. The trend is to make the ice by quick freezing methods in machines instead of freezing it in 300-lb. blocks and then crushing the block so carefully formed.

ANCHOR ICE

Anchor ice is the American name applied to ice that forms on the bottom of rapidly flowing, rocky bottom streams. Its existence can best be explained by the fact that there is at the bottom of rocky streams a considerable quantity of water that has a very slight movement. In very cold weather, rapidly flowing water may reach temperatures as low as 26° F. without actual solidification. Thus, it may occur that the water retarded between the rocks at the bottom will actually solidify before the freezing of the

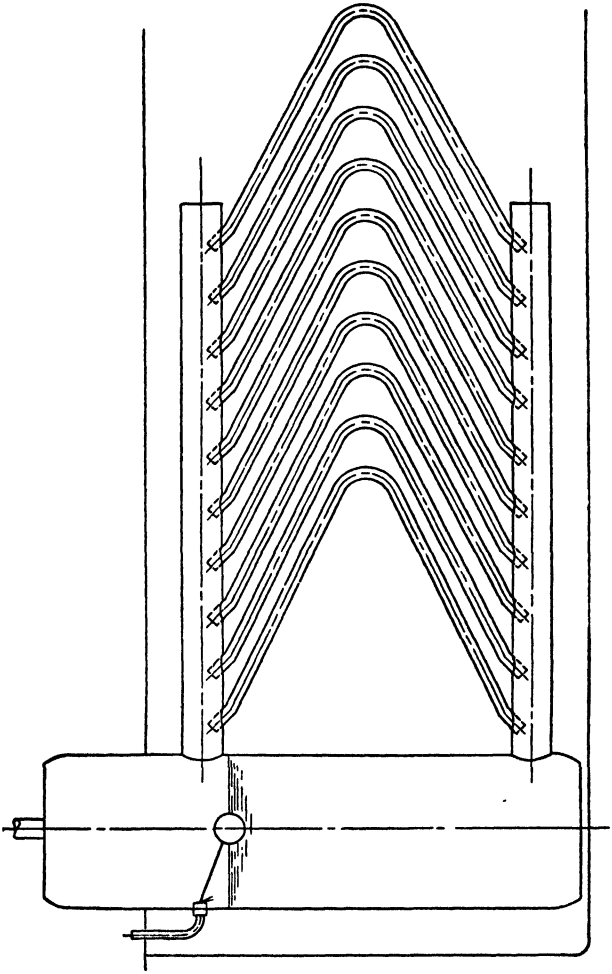

FIG. 14-3. Sectional view of York trunk coil for freezing tanks. *Courtesy of York Ice Machinery Corp.*

rapidly moving water at the surface. This ice usually fixes itself to the surface of the rocks; thus, the name of "anchor ice."

Some Canadian observers report that they have witnessed the presence of anchor ice when there was also ice on the surface. This is made possible by the formation of anchor ice at some period of cold weather and the subsequent freezing of the surface water with the advent of still colder weather.

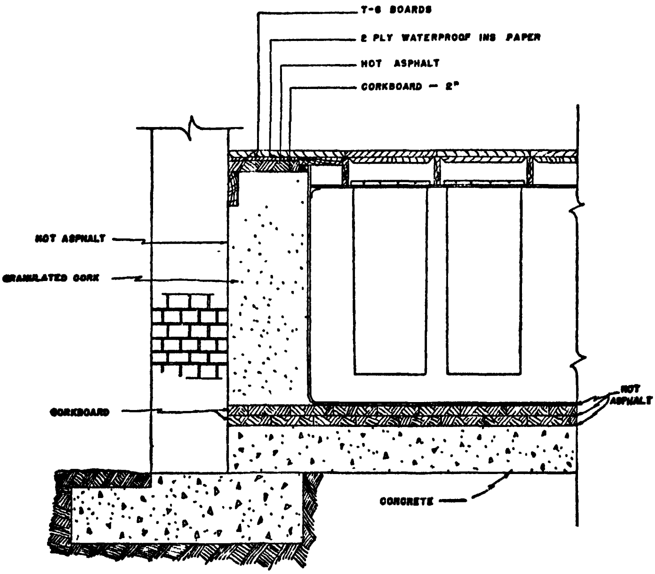

FIG. 14-4. Typical layout for insulating an ice tank.

ENGINEERS' INSPECTION OF ICE TANKS *

(a) If tank and cooler coils have not been thoroughly cleaned of oil for several years, they should be heated up to approximately 50° and thoroughly blown out.

(b) If brine is treated to inhibit corrosion, check the concentration. Check agitators to see that they are not pulling air into brine. Based on experience, 350 ppm of chromate give good protection. Get advice of competent chemist on your particular problem and follow his recommendation.

(c) If forecooler coils have not been used for several years, check them for possible ammonia leaks.

* Check list compiled mostly by R. A. O'Neil. Published by permission of Southwestern Ice Manufacturers Association.

Inspect and check the following:	*Checked By*	*Date Checked*
(1) All coil stands and bolts. Tighten and replace where necessary		
(2) All agitator shafts, packing, and impellers		
(3) Can submergence to determine if it is maximum possible. This may call for raising cans near agitator discharge. Keep record of brine level on daily engine room log sheet		
(4) All agitator bulk heads and partitions for possible short circuiting of brine		
(5) All air headers, laterals, etc., for possible failure due to corrosion. Replace before season starts		
(6) Spare fittings and anticipate your requirements. Place orders for repair parts in plenty of time		
(7) Cork insulation around tank and refill where necessary. Stop possible water leaks into insulation		
(8) All tubes and clean if covered with lime deposit		
(9) Brine density and keep at 70–75° Salometer		
(10) Ice hoist and order repair parts at once, including contacts for control. One spare hoist cable should be on hand at all times		
(11) Can dogs to see that they are safe and will not slip out of can		
(12) Use and care of can filler, core sucker, and can filler hose. Handle with care for replacement might be difficult		
(13) Short and broken pieces of tubing and salvage with all air fittings which have been dropped into the ice tank		
(14) Size of core being pumped and determine if it could be decreased. A good method to secure additional tonnage without sacrifice of quality is to adopt more care in preventing excessive core waste		
(15) All expansion and float valves, and reseat or repair where necessary		
(16) Accumulator oil drain and see that it is open		
(17) Core pump for worn bearings, clogged strainer, or ejector jet		
(18) Brine velocity. In tanks with coils between cans brine velocity should be 25 ft. per min. or better. Trunk type coils are considerably higher, some going as high as 175 ft. per min. through the trunk		
(19) All can retainers to see that cans are not floating which retards freezing and possibly cuts air off, resulting in cans of white ice		
(20) Volume of air being used. Orifices may be enlarged due to many causes, and volume of air may be more than required		
(21) Record of refrigerant in receiver. Avoid operating with liquid seal broken		

	Checked By	*Date Checked*
(22) Water analysis and, if possible, use forecooler to secure increased tonnage when required. Check connections and avoid high superheat by using separate compressor on forecooler when possible..	________	________
(23) Possible costs and materials required to place any idle equipment into operation. Furnish this to the management for emergencies................	________	________
(24) Grounding of motors operating agitators, hoists, etc. A B C—Always Be Careful...............	________	________

THE ICE-PLANT LOAD AND THE POWER RATE

Few industrial loads are as desirable at central stations as the motor-driven ice plant. Figure 14–5 gives a characteristic industrial power and lighting load by seasons of a typical central station. Peak loads exist almost universally in the mid-winter months when heavy lighting and power demands occur simultaneously. With the coming of summer the lighting loads fall heavily, and the industrial loads are usually affected downward by vacation influences and similar effects.

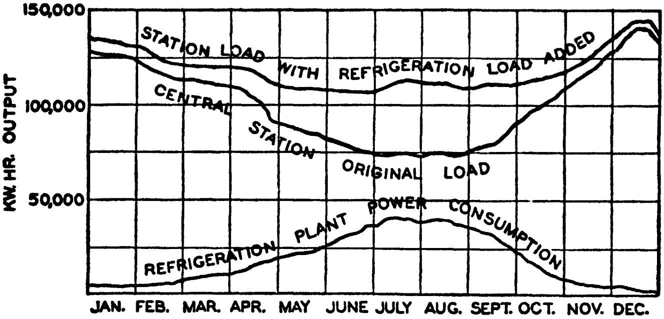

FIG. 14–5. Desirable effect of ice plant load to central stations.

Ice-plant load superimposed upon such a curve scarcely adds anything to the winter peak, whereas the summer load of the typical ice plant fills in the depressions of the central station load curve. In addition to this, the monthly load factor of the ice plant is exceptionally good. In the period of summer, demand load factors of 70% are common, and for any one month a load factor of 40 to 50% can readily be maintained.

A further factor that makes the refrigerant compressor a desirable load for the central station is that it adapts itself so readily to synchronous motor drive. In nearly every locality, a synchronous motor reactive load is welcomed by the central station to balance up the inductive loads on the system.

DUMP-POWER RATES

Although dump power was a term originally applied only to the surplus available water power that could not be retained in storage but which would be lost over the spillway if not used in a given time, it is now equally applied to the unused part of the central station's capacity, whether steam or water power.

In agreements to remain off the power line when the daily peak load is being supplied by the central power station to its customers, owners of ice plants often can secure a very advantageous rate for winter filling of storage houses. In some states such an agreement must be approved by the rate commission, but usually the rate commission will extend its approval on request of the power company.

From previous discussions, the factors governing the power required per ton of ice produced have been explained. For standard conditions, a theoretical power requirement of 0.97 hp. per ton of refrigeration per 24 hrs. is required. When allowance is made for volumetric efficiency and machine losses, this is increased to nearly 1.4 hp. per ton.

To this power requirement must be added the power necessary to drive the auxiliaries such as circulation pumps, and compressors, and similar pieces of equipment.

The high average records of the electric-driven machines in actual service today over periods of one month when using cold condensing water are 30 to 38 kwh per ton of ice produced. With warm condensing water this power consumption will increase to from 40 to 52 kwh per ton of ice.

At 36 kwh per ton of ice produced in 24 hrs., the hourly rate per ton is 1.5 kw per ton of ice, or the equivalent of about 2 hp. When it is considered that a ton of ice is equivalent to 1.3 tons of refrigeration on the basis of 52° F. can water and 16° F. ice, and that the above 2 hp. includes the driving of necessary auxiliary units, it is good evidence that the ice-making industry is approaching closely to its theoretical possibilities.

HOW TO KEEP THE MONTHLY ELECTRICAL DEMAND LOAD FACTOR HIGH

Some engineers question the possibility of keeping the load factor high for each month when such a load factor is based on the maximum demand. They argue that when the machine is running it will require virtually full-load kilowatt input, and to keep the load factor high it would be necessary to operate more than 50% of the time. Often this is undesirable in the wintertime when the demand is light.

Such a problem should be met in the design of the plant. Instead of installing large compressors it is often desirable to install three or four small compressors, each one individually driven. When a small monthly output is required, one machine may carry the load at a high load factor. In the spring and fall, when the demand is still at a low point, it may be necessary to run two of the machines. But the load factor would still remain above 50%, as is evidenced by the fact that one machine could not produce the output.

When heavy demand of summer arrives, all the machines can be put into operation and still give a demand low enough as compared with the total power consumption to keep the load factor above 50%.

COST OF EQUIPPING PLANT

Cost per ton of ice capacity is greater for small plants than for large plants. This holds true either for an electric-driven or steam-driven plant. The curves of Figure 14–6 give the approximate cost per ton, at present prices, for plants of from 8 to 400 tons daily ice-making capacity.

Space requirements of a slow-speed engine drive have always been a matter of much concern where space was at a premium. Vertical machines of the slow-speed type have always required so much overhead room to permit the pulling of the piston whereas the horizontal machines have been equally disadvantageous in that they require such a large floor area. The installations of electric machines replacing these steam units often occupy only 20 to 25% of the space occupied by units of similar capacity.

Labor saved in the electric-driven plant is largely that of the boiler room. This is on the assumption that, in the cost of coal, delivery charges to the boiler room are included.

The item of maintaining the operating expense nearly proportional to the output is of great importance to the ice industry. Theoretically, the winter season of the year should make possible the production of ice at a low cost—in fact, much lower than in summer. The available condensing water is very cold, and this gives low head pressures on the compressor. The can water is usually near freezing when the cans are filled, and melting losses are negligible. Yet in spite of these favorable factors, the cost per ton of producing ice with the steam plant soars upward in winter because of the low efficiencies of the underloaded boiler, engine, and boiler room force.

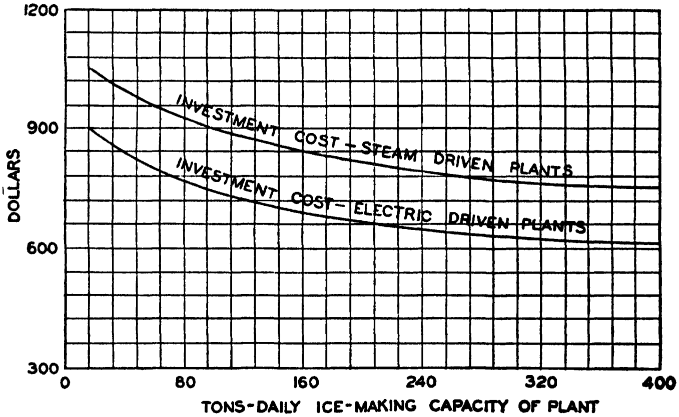

FIG. 14-6. Overall cost per ton—steam and electric plants.

WHERE THE STEAM-DRIVEN PLANT CAN COMPETE

Steam-driven compressors can compete where the distributors of industrial current fail to realize the desirability of the ice-plant load and demand an excessive rate. Further, if refuse fuel is available for making steam, or if the ammonia compressor is only one of several units operated from a central boiler plant of sufficient size to insure efficient operation, then there is little possibility of the electric machine competing with the steam drive, unless an exceptionally low current rate is available.

For very low temperature work, the steam absorption unit usually cannot be successfully replaced by the electric-driven compressor since the cost of operating the compressor increases too rapidly with the lowering of suction pressures.

SPECIAL MACHINE-MADE ICE

FlakIce. FlakIce is a machine-formed product developed by Dr. Crosby Field for packing ice cream, lettuce, celery, milk and similar products. It is produced on cylindrical drums made up of flexible metal. The ice is broken from the cylinder by distorting the surface. The "FlakIce" produced is of a curvilinear form. This curvature aids in packing to prevent the mass from becoming solid, since the curved forms do not readily adjust themselves to fit together.

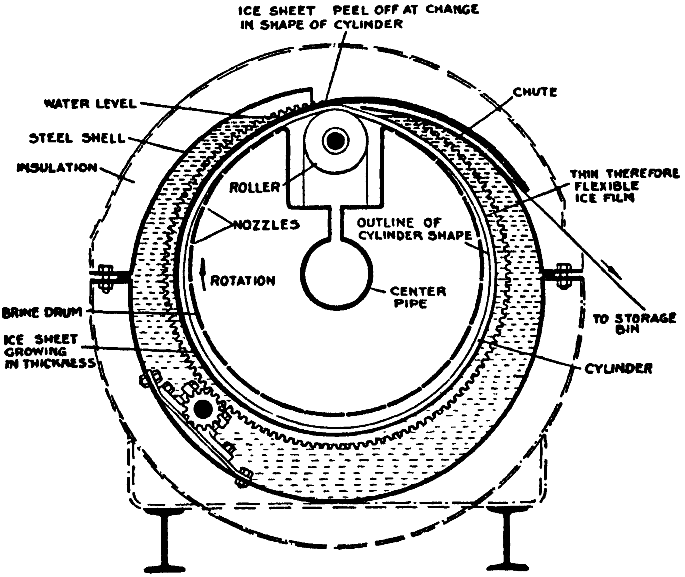
ICE SHEET PEEL OFF AT CHANGE IN SHAPE OF CYLINDER
WATER LEVEL
STEEL SHELL
INSULATION
CHUTE
ROLLER
NOZZLES
OUTLINE OF CYLINDER SHAPE
THIN THEREFORE FLEXIBLE ICE FILM
ROTATION
CENTER PIPE
BRINE DRUM
ICE SHEET GROWING IN THICKNESS
TO STORAGE BIN
CYLINDER

FIG. 14–7. Cross section of FlakIce machine.

The interior of the flexible cylinder in Figure 14–7 is kept full of cold brine, constantly being replenished and agitated by incoming brine flowing through nozzles in the internal drum and along the interior surface of the flexible cylinder and thence out of the machine.

A small amount of water to be frozen is maintained between the exterior surface of the cylinder and the interior surface of the insulated cylindrical tank and at a level just below the top of the flexible cylinder.

The frozen water ribbon reaches the desired thickness at the instant a cylinder leaves the water and just shortly before passing over the deflecting roller. In passing over the deflecting roller the metal cylinder and the ice separate, the latter leaving the machine in a continuous ribbon of the desired and predetermined dimensions.

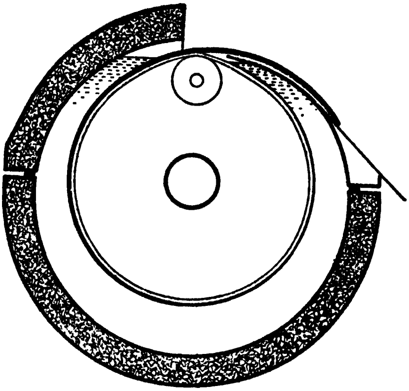

FIG. 14–8. Schematic diagram—how frozen water-ribbons peel.

The separation is due entirely to the difference in elasticity between the ice and the cylinder metal to which it is frozen, and to the slight change in the shape of the latter while passing over the deflecting roller.

Tube-ice. The tube-ice machine is a development of the Henry Vogt Machine Company. As is shown in Figure 14–9, water is delivered to the top of the steel shell into the water distributor. The low-pressure refrigerant is admitted into the shell and surrounds the tubes. The water is frozen in the tubes either as a solid or as a hollow cylinder. A timer on the machine is adjusted to provide either hollow or solid cylinders.

The ice is loosened from the tubes by exchanging the cold refrigerant around the tubes for a warm high-pressure refrigerant gas which melts the ice sufficiently to free it from the tube surface.

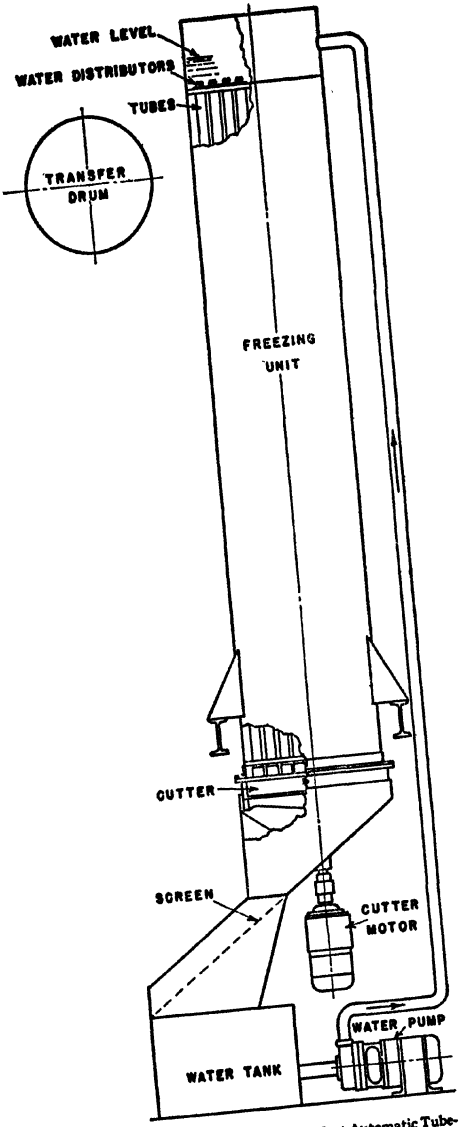

Diagram of a typical single unit Vogt Automatic Tube-Ice Machine illustrating the general arrangement.

FIG. 14-9.

The released ice cylinders drop by gravity to a revolving cutter at the end of the metal tube in which the ice was formed. This cutter is adjusted to give tubes of a desired length.

PakIce. PakIce is the trade name for ice manufactured with Vilter PakIce equipment. PakIce machines are available in both vertical and horizontal design and in capacities up to 36 tons per day.

PakIce can be made available in either snow or cube form. As it comes directly from the freezing drums it is in the form of snow.

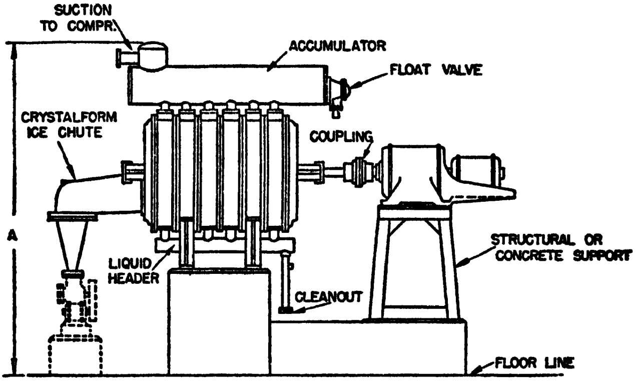

FIG. 14–10. PakIce freezer.

From the drums it can be taken directly in the snow form or passed on to the briquetting machine.

The machine is built up of corrugated rings to form a drum around which direct expansion ammonia is circulated in the annular spaces around the drum. Water is sprayed on the freezing surface within the drum. This freezes the water immediately. A series of rotating cutters or knives shears the ice from the freezing surfaces as fast as it forms. The ice flows out of the freezer drum into the briquetting machine.

Figure 14–10 shows the line drawing of the freezing drum feeding into the briquetting press. The press is shown by dotted lines.

ICE MELTING RATES

Early experiments by Scates * and Woolrich and subsequent verification by Willis Short and Woolrich † proved that the ice melting rate is greatly increased when the surrounding air humidity is high.

TABLE 14-3. U. S. SALES OF MANUFACTURED ICE
(In Tons)

Year	Tons	Percentage of Change
1919	31,616,000	
1920	32,841,000	4.0 Increase
1921	35,317,000	7.6 Increase
1922	36,428,000	3.2 Increase
1923	39,916,000	9.6 Increase
1924	41,292,000	3.4 Increase
1925	46,864,000	13.4 Increase
1926	45,927,000	2.0 Increase
1927	47,543,000	3.4 Increase
1928	50,994,000	7.25 Increase
1929	53,544,000	5.0 Increase
1930	56,239,000	5.34 Increase
1931	57,365,000	2.05 Increase
1932	43,826 000	23.6 Decrease
1933	39,005,000	11.0 Decrease
1934	39,785,000	2.0 Increase
1935	34,325,000	13.7 Decrease
1936	39,131,000	14.0 Increase
1937	35,372,000	9.6 Decrease
1938	32,896,000	7.5 Decrease
1939	33,458,000	2.0 Increase
1940	30,280,000	10.4 Decrease
1941	34,034,000	12.25 Increase
1942	35,686,000	4.6 Increase
1943	43,001,000	20.3 Increase
1944	49,752,664	15.7 Increase
1945	52,500,000	5.5 Increase
1946	54,400,000	3.6 Increase
1947	52,500,000 (Approx.)	3.5 Decrease

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* Scates, P. W., "The Rate of Ice Melting," *Refrigerating Engineering*, July, 1931.

† Willis, A. H., Short, B. E., and Woolrich, W. R., "Ice Melting and Freezing Rates," *Refrigerating Engineering*, May, 1940.

When the humidity and refrigerator temperature were held constant, the melting rate was a function of the surface exposed for still air. When the air velocity was increased, the melting rate was likewise increased.

In some of the newer designs of ice boxes compensation has been made for these effects by equipping the box with a small circulating fan. When the ice block area is large, the fan operating time is very short; but as the ice block area is reduced, the running time of the fan is greatly increased by the thermostatic regulator, thus providing a relatively uniform temperature within the box.

SECTION XV

COLD STORAGE, FOOD PRESERVATION AND FUR STORAGE

COLD STORAGE

By definition cold storage is the process of preserving perishables on a large scale by one or more of the refrigeration processes.

In the typical cold-storage house the space may be divided into (a) cooler, (b) carrying freezer, and (c) sharp freezer space. The cooler rooms, in turn, may be classified as warm coolers, chill rooms, and holding rooms.

The cooler rooms are those held above the freezing temperature of the perishables. Rooms that are kept above 40° F. are for storage of those products that preserve best at relatively high temperatures. Those that are kept at temperatures between 40° F. and 30° F. are either for chilling incoming products or for long-term holding storage.

Carrying freezer rooms are generally held between −20° F. and +15° F. for the long-term holding of frozen products. Sharp freezer storage is used for quick freezing of unfrozen goods with little change in the temperature of the freezing room. Commonly the product is later transferred to the carrying freezer rooms.

Whereas all of these several processes are carried on in most cold-storage houses, for the sake of clarity the first discussion will be devoted primarily to the preservation of products by cooler storage, and the subsequent section will be given over to freezer storage.

FOOD PRESERVATION

To preserve food, relatively low temperatures must be maintained. Temperature control alone, however, is not enough for successful food preservation. The condition of the atmosphere in which the food is being kept must be closely controlled if the best results are to be obtained. Successful food preservation requires:

(1) Low temperature.
(2) Correct humidity.
(3) Proper atmosphere.
(4) Odor control.
(5) Sound and suitable foodstuffs for storage.

The low temperatures required vary greatly with the foodstuffs to be preserved. Even in any one class, considerable variation in requirements is necessary. For instance, the desirable temperature for apples and grapes is lower than that for lemons and grapefruit. In general, the fruits high in sugar content preserve better at temperatures lower than those desirable for sour or more acid fruits.

In vegetables, the sugar does not seem to have this preserving effect. Sweet potatoes, for instance, are much more difficult to keep than Irish potatoes. Sweet potatoes are chilled if kept at temperatures below 45° F., whereas Irish potatoes can reach 38° F. without any bad effects.

In cold-storage practice, humidity control is, from the standpoint of operation, a companion factor to low temperature maintenance. The foods that are high in moisture will wither or evaporate if too dry an atmosphere is maintained, whereas excess moisture will give a musty odor to the foods stored.

Vital Heat. "Vital Heat" is a term applied to the heat evolved by life processes such as respiration and oxidation of living organisms. In the respiration process of plants and fruits, carbon dioxide is given off.

L. A. Hawkins states that according to Van't Hoff's law, the amount of vital heat given off by fruits and vegetables should increase two or three times for each 18° F. or 10° C. rise in temperature. In dealing with green flowers in the presence of light, a complementary process of photosynthesis will be in effect. In the photosynthetic action, oxygen is given off and carbon dioxide is absorbed. Only in the presence of light and green chlorophyll will photosynthetic action take place.

The researches of E. S. Johnson and E. D. McAlister of the Smithsonian Institution indicate that photosynthesis ceases almost immediately when the room is darkened.

TABLE 15-1. VITAL HEAT

(Approximate Rate of Evolution of Heat by Certain Fresh Fruits and Vegetables When Stored at Temperatures Indicated)

COMMODITY	TEMP. (° F.)	BTU PER TON OF FRUIT PER 24 HOURS
Apples	32	660- 880
	60	4,400- 6,600
	85	6,600-15,400
Bananas		
Green	68	8,360
Turning	68	9,240
Ripe	68	8,360
Beets	32	1,166
	60	8,476
Cantaloupe	32	213
	60	3,938
Carrots	32	814
	60	8,806
Celery	32	704
	60	5,862
Cherries (sour)	32	1,320- 1,760
	60	11,000-13,200
Grapefruit	32	460
	60	2,770
	80	4,180
Grapes	35	660- 1,100
	60	2,200- 2,640
	80	5,500- 6,600
Lemons	32	580
	60	2,970
	80	6,200
Lettuce	32	638
	60	22,660
Onions	32	660- 1,100
	70	3,080- 4,180
Oranges	32	690- 900
	60	2,710- 2,970
	80	8,000
Peaches	35	1,540- 1,980
	60	6,600-13,200
	80	15,400-22,000
Pears (Bartlett)	32	660- 880
	60	8,800-13,200
Peppers	32	550
	60	3,322
Potatoes	32	440- 880
	70	2,200- 3,520
Raspberries	35	4,400- 6,600
	60	15,400-17,600
Strawberries	32	2,732- 3,800
	60	15,640-19,140
	80	37,220-46,440
String beans	60	10,802
Sweet corn	32	2,640
	60	8,118
Sweet potatoes	40	880- 1,320
	85	6,600- 8,800
Tomatoes (mature green)	32	0
	60	2,574
Turnips	32	66
	60	682

Values mostly from U.S.D.A.

COOLER STORAGE OF FRUITS

Apples. Apple cold storage is very successful. Differences in apple varieties are a determining factor in length of storage and the temperature of holding. In general, however, a holding temperature just above 35° F. is recommended. Some varieties, like the Jonathan, can be held successfully at 32° F., whereas the Rome Beauty does better at 38° F. Summer apples may usually be held successfully for a period of a few weeks but are not good keepers and are usually moved on to the market quickly to avoid competition from the fall and winter varieties.

Early winter varieties, Jonathan, Grimes Golden and McIntosh, may be stored from two to four months.

Late winter varieties, Baldwin, Ben Davis, Black Arkansas, Delicious, Greening, Rome Beauty, Newton, York, Spy, Winesap, and Yellow Twig, may be held from four to six months if stored at low temperatures.

Long-term storage can be aided by wrapping each apple in oiled paper and cooling to the holding temperature immediately.

Berries. Strawberries, raspberries, blackberries, dewberries, Boysenberries and loganberries must be placed in cold storage in good, firm condition. If any moldy growth is found on the berries, no attempt should be made to store.

Freshly picked, dry, firm berries will keep from seven to ten days if held at 32° F. and if they are not bruised by rough handling.

Cherries. A limited quantity of cherries find their way into the cooler rooms of the cold-storage plant. Some sweet cherries will keep in storage for two weeks. Most varieties should be moved in one week. They should be held at 32° F.

Sour cherries will not keep as well as sweet cherries. Best keeping varieties are Black, Bing, Coe, Eagle, Pontiac, Sanbert, Tartarian and Windsor.

Grapefruit. Grapefruit may give some trouble in storage if not carefully inspected. Stem-end rot is common in Florida and Texas grapefruit. This can be partly controlled by treating the grapefruit with either a 2% borax solution or sodium metaborate and storing at 40° F. Where stem-end rot is not common, lower temperatures can be used. The humidity should be controlled to not below 85% and not over 90%.

Grapes. Grapes should be held at 33° F. to 35° F. Most American varieties, such as Concord, Delaware, etc., keep best in open baskets or crates, whereas European varieties, such as Tokay, Thompson Seedless, Emperor and Malaga, keep well in granulated cork. The American varieties are not as good for long storage as the European.

Lemons. Lemons belong definitely in relatively warm storage. They store best at from 50° F. to 55° F. Lemons should be wrapped in paper for long storage.

Oranges. Oranges, like grapefruit, might profit by treating before storage with a 2% solution of borax. This will control the blue mold. The storage temperature should be at 40° F. Wrapping improves the storing, probably because of a reduction of bruising as well as protection from adjacent fruit.

Oranges should not be stored for long periods. A one- to two-month storage period is usually the maximum for oranges.

Pears. Pears vary widely, and the storage period is affected by variety. A few degrees lowering of the temperature of storage increases the storage time considerably. At 31° F. Bartlett, Bosc and Kieffer pears can be stored for two to three months, Comice and Hardy varieties for three to four months, Anjou and Clairgeau for four to five months, and Easter Beurre and Winter Nelis for six to seven months.

Plums and Prunes. Plums are a short storage item of cold storage. They lose flavor quickly and are generally held in storage only for the brief period required for distribution to the retailer. Climax, Tragedy, Grand Duke, Kelsey, Satsuma and Wicksen can be held for three to eight weeks but usually become soft and less palatable. The harder plums such as Abundance, Damson and Wild Goose will keep better than some of the larger soft varieties, but since most of these go into canning and are not eaten in the raw state, there is not much incentive to preserve them for long periods by cold storage. The best storage temperature is 31° F. to 32° F.

SPECIAL ATMOSPHERIC CONDITIONING OF FRUIT STORAGE

In the United States and Canada, where competitive conditions require that fruit shall be moved with a minimum of handling, the special treatment of fruits by carbon dioxide or by a mixture of carbon dioxide and oxygen has not been enthusiastically accepted. In England and on the European continent, where loss by decay is economically more serious, the preservation of certain fruits by controlled refrigerated atmospheres is accepted.

Apples take the first place of those fruits that are successfully preserved for longer than normal periods by carbon dioxide cold storage. McIntosh, Cortland, Grimes Golden and Northwestern Greenings all respond effectively to a conditioned atmosphere of 5% carbon dioxide and 2% oxygen. Reports indicate that the normal keeping life can be increased two or three months by stor-

ing at 40° F. with this atmospheric control. Furthermore, the condition of the apples after they leave the cold-storage warehouse and go to the market-shelves remains superior to that normally experienced with cold-storage apples.

As practised, the cold-storage room to be used for conditioned storage is equipped with an atmosphere scrubber. The room is precooled, then filled with freshly picked fruit and sealed. The conditioned atmosphere of carbon dioxide, oxygen and air is scrubbed as a continuous process. When the room is to be opened, precautions are taken to ventilate it for several hours before entering.

Reports on the conditioned storage of other fruits, although conflicting in experiences recorded, indicate that the storage of berries, oranges, grapefruit and pears can be improved by refrigerated carbon dioxide and oxygen storage. There is no conclusive evidence that the fruits that have pits, such as apricots, plums and peaches, are benefited.

TABLE 15–2. COOLER STORAGE TEMPERATURES AND MOISTURE CONTENT OF FRUITS

Fruits	Average Per Cent Water in Fruit	Temperature at Which Fruit is Usually Kept, °F.	Fruits	Average Per Cent Water in Fruit	Temperature at Which Fruit is Usually Kept, °F.
Apples.	84	32–35	Grapefruit . .	89	40–42
Apricots...... ..	86	35–40	Grapes. .	82	33–35
Bananas..	75	50–60	Lemons	89	50–55
Blackberries .	86	32–34	Oranges. .	87	40–50
Cantaloupes .	89	35–40	Peaches. . .	87	32–34
Cherries.... . .	84	32–34	Pears.... ..	83	31–32
Cranberries. .	88	33–36	Pineapples.	85	32–40
Currants, dried	28	40–45	Plums and prunes	86	31–32
Dates.... ...	22	50–55	Strawberries. .	90	32–34

The heavy demand for all fruit products during the war made special treatment of fruits unattractive, since the fruit would sell for high prices without such treatment. As the American markets become more competitive, new interest and enthusiasm can be

TABLE 15-3. COMPOSITION OF FRUITS (EDIBLE PORTION)*

Name	Percentage by Weight							Parts per Million		Alkaline (+) or Acid (−) Effect	Calories per 100 Grams	Vitamin Content per 100 Grams †			
	Protein	Carbohydrate Other than Fiber	Fat	Crude Fiber	Ash	Calcium	Phosphorus	Iron	Copper			A	B_1	C	B_2
Apples	0.3	13.9	0.4	1.0	0.3	0.007	0.012	3.6	1.0	+ 3.7	60	50	45	6	73
Apricots	1.0	12.3	0.1	0.6	0.6	.014	.025	6.1	1.8	+ 6.1	54	4000	30	11	75
Avocados	2.0	4.0	17.2	1.4	1.3	.045	.044	5.7	2.1	+10.7	179	130	100	28	90
Bananas	1.2	22.4	0.2	0.6	0.8	.009	.031	6.4	2.1	+ 5.6	96	400	60	28	90
Blackberries	1.2	7.8	1.1	4.1	0.5	.017	.030	9.1	1.6	+ 6.9	46	83	45	3	...
Blueberries (huckleberries)	0.6	13.9	0.6	1.2	0.3	.025	.020	8.0	1.1	+ 2.7	63	100	45	15	18
Cherries	1.1	14.5	0.5	0.3	0.6	.019	.031	4.0	1.4	+ 4.5	67	200	50	12	...
Cranberries	0.4	9.9	0.7	1.4	0.2	.046	.020	4.4	0.9	......	48	70	0	15	0
Currants	1.6	9.5	0.4	3.2	0.6	.060	.036	6.3	11.2	+ 6.3	48	400	30	100	...
Dates, dried	2.2	73.0	0.6	2.4	1.8	.065	.056	36.0	3.8	+11.0	306	210	72	0	30
Figs, dried	4.0	62.6	1.2	5.8	2.4	.162	.116	28.7	3.5	+32.9	277	75	100	0	100
Gooseberries	0.8	7.6	0.4	2.5	0.4	.040	.050	4.7	0.8	+ 3.3	37	380	150	25	...
Grapefruit	0.5	9.8	0.2	0.3	0.4	.021	0.20	2.7	0.3	+ 7.0	43	20	72	42	100
Grapes	1.4	14.4	1.4	0.5	0.5	.019	.031	7.3	0.9	+ 4.0	76	50	45	5	25
Guavas	1.0	11.6	0.6	5.5	0.7	.015	.016	3.0	0.2	+ 8.0	56	200	150	370	90
Lemons	0.9	7.8	0.6	0.9	0.5	.036	.022	6.0	0.4	+ 5.0	40	0	60	46	...

Limes	0.8	8.6	0.1	0.3	0.6	.055	.036	..	9.7	...	39	130	..	36	...
Loganberries	1.0	13.6	0.6	1.4	0.5	.035	.024	13.7	1.4	+ 7.3	64	....	33	35	...
Mangos	0.7	16.2	0.2	1.0	0.5	.005	.016	3.0	0.1	+ 5.0	69	1500	60	60	200
Melons—Cantaloupes	0.6	4.0	0.2	0.6	0.6	.017	.015	5.1	0.6	+ 7.5	20	300	50	30	75
Honeydew	0.6	7.5	0.2	0.5	0.6	.....	...	...	0.7	.....	34	...	..	94	...
Muskmelons	0.6	5.4	0.2	0.5	0.6	.016	.015	3.9	0.6	+ 7.5	26	2400	57	25	75
Watermelons	0.5	6.3	0.2	0.6	0.3	.011	.003	2.3	.07	+ 2.7	29	500	60	7	35
Nectarines	0.5	15.6	0.1	0.4	0.5	.004	.024	4.6	0.6	+ 6.2	65	2800	72	25	...
Olives, green	1.5	2.8	13.5	1.2	5.8	.122	.014	2.9	1.8	.	139	190	8	0	0
Oranges	0.9	10.6	0.2	0.6	0.5	.045	.021	5.2	0.8	+ 5.6	48	90	78	48	60
Papayas	0.6	9.1	0.1	0.9	0.6	.019	.013	3.0	0.1	. .	40	3000	75	42	150
Peaches	0.5	11.4	0.1	0.6	0.5	.016	.024	3.5	0.9	+ 5.9	49	1700	20	8	64
Pears	0.7	14.4	0.4	1.4	0.4	.015	.026	3.5	1.0	+ 4.2	64	15	60	5	76
Persimmons	0.8	32.0	0.4	1.5	0.9	.022	.021	2.7	.	..	135	2600	0	18	...
Pineapples	0.4	13.3	0.2	0.4	0.4	.018	.028	3.7	0.7	+ 6.8	57	200	90	38	55
Plums	0.7	12.4	0.2	0.5	0.5	.020	.027	5.6	1.5	.	54	360	100	5	45
Pomegranates	0.6	17.4	0.2	0.3	0.5	.011	.105	7.8	0.7	+ 3.5	74		.	6	100
Prunes, dried	2.3	69.4	0.6	1.6	2.1	.054	.105	28.5	4.1		292	1600	180	0	650
Quinces	0.3	12.1	0.1	1.8	0.4	.014	.021	10.1	1.4	+ 4.9	51		.	9	..
Raisins	2.3	69.5	0.5	1.7	2.0	.064	.132	43.4	2.0	+33.5	292	0	100	0	130
Raspberries, black	1.5	12.1	1.6	3.5	0.7	.049	.052	8.8	1.4	+ 3.8	69	0	21	30	...
Raspberries, red	1.1	11.6	0.6	2.8	0.5	.041	.035	8.8	1.3	+ 6.0	56	130	21	30	...
Strawberries	0.8	6.9	0.6	1.2	0.5	.041	.028	6.8	0.2	+ 5.5	36	50	33	60	500
Tangerines	0.8	9.9	0.3	1.0	0.7	.042	.017	6.1	0.9	+ 5.3	46	300	120	48	40

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* Values mostly from Nutritional Charts, 1942, H. J. Heinz Co., by permission.

† Vitamin A is expressed in International units, vitamin B_1 and B_2 in micrograms, and vitamin C in milligrams per 100 grams or ml. of food.

anticipated in conditioned cold storage of those fruits that do not keep for long periods in the common atmosphere of commercial cold-storage plants.

Waxing of Fruit. The use of wax for oranges and apples has been practised for some years. The reports on its effectiveness have been most conflicting. The wax treatment is recognized as a satisfactory surface coating to give the required commercial polish, but authorities are not in accord on the success of such polishing waxes to inhibit mold growth.

Combined with the waxing process in citrus packing sheds will be found ethylene gas treating rooms to give oranges a higher color. Citrus fruits are likely to come from the tree in many varying shades, from a green yellow to a deep orange. The gas treating-rooms are accepted as the commercial method of grading the fruit to a uniform color. Many unestablished claims to the preserving effect of this treatment are also made.

Ozone. Ozone is a triatomic form of oxygen that is very unstable. It is produced in nature by lightning discharges and its presence can sometimes be detected in the atmosphere during an electrical storm.

Ozone is a most active oxidizing agent. Its virtue as a destroyer of spores and germs is due largely to its oxidizing power, but it is this same oxidizing activity that makes its use in rooms that contain bacon, butter, bananas, cream, lard and beef fat a matter that must be given close supervision.

To prevent the ozone from producing rancid products in the cooler room, it should be used in low percentages, usually not more than 3 ppm. Exposure of most of the spores and bacteria to the atmosphere of ozone for a period of 3 hrs. is sufficient to do the arresting job. Practice varies, but in most cold-storage houses it has been found that one 3-hr. period per day will be sufficient to prevent the spores and bacteria from becoming too prolific. In some houses this practice is changed to one 2-hr. period of ozone treatment each 12 hrs.

Concentrations of 3 ppm and one 3-hr. or two 2-hr. treatments per day will not give serious rancidity troubles and will destroy the greater part of the undesirable bacteria, if the temperatures of the cooler are held below 38° F. In high-temperature rooms no appreciable value can be secured from ozone, and in freezer rooms it is not needed.

The work of Dr. Arthur W. Elwell and others has demonstrated that if ozone is correctly applied it is the best agent for destroying bacteria, spores and bad odors in storage rooms that are maintained between 30° F. and 38° F.

COOLER STORAGE OF VEGETABLES

Asparagus. Asparagus is a sensitive vegetable to store. Stocks that have been cut for some hours should be chilled immediately to 32° F. and moved out to the market within three to five days. A relative humidity of 90% will be required to keep it from drying out. If the stocks are brought into cold storage in a garden-fresh condition and then packed in small bunches in moist covering, the length of keeping time can be greatly increased.

Beans. Green beans usually come into the cold-storage plant in hampers and crates. Beans grow in such a wide variety of types that new experiences in keeping them are very common to every cold-storage plant. Green beans are very sensitive to cold temperatures and although some storage houses attempt to hold them at 32° F. this is likely to result in frozen stock if care is not exercised. The best results with all beans except limas are secured if stored at 38° F. and 85% relative humidity.

Lima beans, both shelled and in the pod, should be kept at 32° F. and 85% to 90% relative humidity. The beans will probably keep somewhat longer if left in the pod than when stored shelled. The pod will not appear as salable as the shelled beans, since the pods may discolor slightly without any similar deterioration of the beans. Shelled beans of the Lima variety should keep two weeks if strictly fresh when brought into the warehouse.

Beets. Beets come to the cold-storage rooms either as topped mature beets or as young bunch beets with their tops. If the beets are mature and topped they will keep three to five months if held at 34° F. to 35° F. at 90% to 95% relative humidity. Young beets with tops should be moved to the market in five to ten days when stored at 32° F. and 90% humidity.

Broccoli. Increased quantities of broccoli are appearing on the market. It is a problem item of the cold-storage plant. It should be kept at 32° F. and 90% humidity. If very fresh when it is brought to the cooler room, it should keep for eight or ten days without discoloring. If some enzyme action has already set in before cooling, it will be desirable to market it at once.

Cabbage. Cabbage moves on to the market in extensive tonnages. Although it is easy to keep, slight decay within the stock will cause very offensive odors. For safety, cabbage accepted on a long-term storage consignment should be kept in a separate room for odor control. Cabbage does not freeze readily and can be held at 32° F. and 90% humidity for three to five months. The red and hard varieties will keep longer than the soft head types.

Carrots. Mature topped carrots will keep from one to three months if held at 34° F. to 35° F. and at 90% to 95% relative humidity. Young carrots with tops should be moved to the market within five to ten days when stored at 32° F. and 90% relative humidity.

Cauliflower. Cauliflower will not keep long. As it is received in its white form it is not fully matured and the refrigeration retards further ripening. If kept at 32° F. and 95% humidity it can be kept two weeks in presentable condition for the market.

Celery. Contrary to public belief, celery is not easy to keep in cold storage. It is subject to soft rot, sometimes misnamed by the buyers as brown rot. Celery should be moved immediately to the cooler rooms from the field in crates, then should be stored so that air can circulate freely between each crate. If held at 32° F. and 95% humidity, storage is possible for several months if fresh and rot-free at time of storing.

Sweetcorn. Sweetcorn starts to lose flavor from the time it is picked. Although it might appear satisfactory to the buyer some days after picking, the test of flavor upon eating will reveal that it has become less tasty than fresh corn. The limit of keeping time is two to three weeks if the freshly picked corn is immediately cooled to 32° F. and held at 95% relative humidity.

Cucumbers. A large quantity of the cucumbers going to the market move daily from greenhouses by truck and require no cold storage before consumption. Cucumbers can be stored successfully for one to three weeks at 45° F. to 50° F. at 90% relative humidity.

Lettuce. Hundreds of carloads and thousands of truckloads of head lettuce move to the market each month. Most lettuce is precooled before transporting and quite generally packed in crates, then iced ready for shipment.

Lettuce should be stored at 32° F. and 95% relative humidity. While in storage it should be well ventilated. Under ideal conditions it might be held for three weeks, but most lettuce should be moved out to market within six or eight days.

Onions. Onions come into the cooler in crates and sacks. The sweet varieties will not keep as well as the harder, stronger types.

Onions, garlic and onion sets might all be placed in the same storage room. Usually it is necessary to keep them in a very dry room by themselves. In handling the stored onions, no trace of moisture should be noticeable. A temperature of 31° F. and 70% relative humidity is usually most acceptable. Sweet onions such as the Bermuda varieties should keep from two to three months, and the hard onions such as the Danvers and Weathersfield should keep for six months.

The low temperature of 31° F. will not affect the sprouting of the seed onions.

Since onions should be kept very dry, it is not advisable to remove them from a 31° F. room into warm air without permitting them to warm up in an intermediate cool room. If taken into a warm humid room directly from the storage, the condensation on the onions will be excessive and will cause subsequent decay.

TABLE 15–4. COOLER STORAGE TEMPERATURES AND MOISTURE CONTENT OF VEGETABLES

Vegetable	Average Per Cent Water in Vegetable	Temperature at Which Vegetable is Usually Kept, °F.	Vegetable	Average Per Cent Water in Vegetable	Temperature at Which Vegetable is Usually Kept, °F.
Asparagus	94	32–34	Lettuce	95	32–34
Beans			Onions	88	31–32
Green	89	37–38	Parsnips	80	32–35
Lima	68	32–33	Peas	75	32–36
Beets	89	32–40	Potatoes		
Cabbage	93	31–36	Irish	79	38–40
Carrots	89	32–36	Sweet	70	55–60
Cauliflower	92	30–32	Radish	94	32–35
Celery	94	32–34	Squash	89	55–60
Corn, green	75	32–34	Tomatoes	95	50–55
Cucumbers	96	45–50			

TABLE 15-5. COMPOSITION OF VEGETABLES (EDIBLE PORTION) *

Name	Percentage by Weight							Parts per Million		Alkaline (+) or Acid (−) Effect	Calories per 100 Grams	Vitamin Content per 100 Grams †			
	Protein	Carbohydrate Other than Fiber	Fat	Crude Fiber	Ash	Calcium-	Phosphorus	Iron	Copper			A	B₁	C	B₂
Artichokes (globe)	2.9	8.7	0.4	3.2	1.1	0.031	0.087	9.5	3.1	+ 7.6	50	390	150	11	10
Asparagus	2.2	3.2	0.2	0.7	0.7	.025	.039	9.6	1.4	+ 0.8	23	1,400	180	40	130
Bamboo shoots	2.5	4.3	0.3	0.8	0.8	.005	.040	7.0	2.9	+ 8.0	30	22	54	6	...
Beans, baked	6.0	17.8	0.4	1.0	2.3	.052	.155	32.0	2.3	+ 6.0	99	0	120	0	...
Beans, dried	22.0	58.2	1.5	3.9	3.9	.160	.471	95.2	6.9	+18.0	334	110	400	0	320
Beans, green	2.4	6.3	0.2	1.4	0.8	.046	.136	9.8	1.0	+ 5.4	37	1,200	95	23	150
Beans, dried lima	20.7	57.3	1.3	3.8	3.8	.072	.386	86.2	8.6	+42.0	324	100	510	0	500
Beans, green lima	7.5	22.0	0.8	1.5	1.7	.028	.133	24.0	8.6	+28.4	125	900	340	42	150
Beans, kidney	5.7	15.5	0.4	0.9	1.5	.046	.052	5.7	6.5	+18.0	88	300	210	...	...
Beets	1.6	8.7	0.1	0.9	1.1	.029	.039	8.5	1.9	+10.9	42	50	50	8	70
Beet greens	2.0	4.2	0.3	1.4	1.7	.094	.040	31.3	0.9	+27.0	28	21,000	110	50	370
Broccoli	3.3	4.2	0.2	1.3	1.1	.114	.060	14.3	1.5	+ 9.3	32	9,000	130	80	250
Brussels sprouts	4.4	7.6	0.5	1.3	1.3	.027	.121	11.7	1.0	+11.0	53	400	170	150	75
Cabbage	1.4	4.3	0.2	1.0	0.8	.045	.029	4.3	0.5	+ 6.0	25	38	80	100	66
Cantaloupe	...	...	...	...	...	.....	...	....	...	...	...	.....	..	...	...
Carrots	1.2	8.2	0.3	1.1	1.0	.056	.046	6.4	0.8	+10.8	40	10,000	70	4	65
Cauliflower	2.4	4.0	0.2	0.9	0.9	.123	.061	9.4	1.4	+ 5.3	27	70	170	75	130
Celeriac (celery root)	1.7	7.4	0.3	1.4	0.9	.047	.071	6.0	1.3	+ 8.8	39	......	...	...	...
Celery	1.3	3.0	0.2	0.7	1.1	.078	.037	6.2	0.1	+ 7.8	19	10	36	9	35
Chard, leaves	2.6	4.0	0.4	0.8	1.2	.150	.040	31.0	1.1	+15.8	30	9,000	300	32	140
Collards	3.9	6.0	0.6	1.2	1.7	.207	.075	16.6	...	+	45	8,800	200	70	250
Corn, canned	2.5	19.2	0.9	1.0	1.0	.006	.103	4.7	1.0	− 1.8	95	.....	100	5	100
Corn, green (yellow)	3.7	19.7	1.2	0.8	0.7	.006	.103	4.7	0.6	− 2.0	104	560	150	40	100
Cucumbers	0.7	2.2	0.1	0.5	0.4	.016	.033	3.3	0.6	+ 7.9	13	0	90	10	44
Dandelion greens	2.7	7.0	0.7	1.8	2.0	.084	.035	30.3	1.5	+17.5	45	12,000	200	150	220
Eggplant	1.1	4.6	0.2	0.9	0.5	.011	.034	4.7	1.0	+ 6.3	25	70	60	10	31
Endive	1.6	3.2	0.2	0.8	0.9	.104	.039	12.3	0.9	+ 7.0	21	4,000	100	20	60

Escarole (chicory)	1.6	2.1	0.3	0.8	1.0	.027	.029	10.1	1.4	+ 4.0	18	23,000	75	8	210
Garlic	4.4	19.0	0.2	1.0	1.2	.010	.143	23.0	3.6	......	95	0	...	14	...
Horseradish	3.2	19.0	0.2	2.4	1.8	.119	.070	20.3	1.4	+ 4.8	91	......	...	90	...
Kale	3.9	6.0	0.6	1.2	1.7	.195	.060	25.4	....	+ 7.7	45	11,000	190	150	500
Kohl-rabi	2.1	5.6	0.1	1.1	1.1	.195	.060	6.1	1.4	+ 8.0	32	....	50	50	75
Lambsquarters	3.8	5.7	0.7	2.6	3.0	....	....	...	...	...	44	19,000	..	25	...
Leeks	2.5	6.6	0.4	1.3	1.0	.058	.056	6.5	5.0	+ 7.0	40	25	150	24	...
Lentils, dried	24.7	56.6	1.0	3.3	3.2	.102	.383	76.3	6.6	−16.0	334	200	500	0	400
Lettuce	1.2	2.3	0.2	0.6	0.9	.043	.042	7.0	0.4	+ 7.4	16	200	90	13	100
Marrow, vegetable	0.5	3.4	0.1	0.6	0.4	.014	.013	2.2	0.3	+ 1.9	17	30	45	11	...
Mushrooms	3.9	3.1	0.2	0.9	1.3	.002	.154	18.4	17.9	+ 4.0	30	120	120	8	500
Mustard greens	2.3	3.2	0.3	0.8	1.2	.291	.084	28.7	3.0	...	25	11,000	140	180	370
Okra	1.8	6.4	0.2	1.0	0.8	.072	.062	6.3	2.0	+ 4.5	35	400	130	17	...
Onions	1.4	9.5	0.2	0.8	0.6	.034	.045	4.8	0.8	+ 1.5	45	0	33	20	120
Parsley	3.7	7.2	1.0	1.8	2.4	.045	.029	31.6	2.1	...	53	5,000	80	140	...
Parsnips	1.5	16.0	0.5	2.2	1.2	.059	.076	7.7	1.2	+12.0	75	200	120	40	...
Peas, dried	23.8	54.8	1.4	5.4	3.0	.084	.400	57.0	14.0	+ 5.0	327	5,100	540	0	300
Peas, green	6.7	15.5	0.4	2.2	0.9	.028	.127	20.7	2.4	+ 1.3	92	2,000	390	25	200
Peppers, green	1.2	4.3	0.2	1.4	0.5	.006	.026	4.0	1.0	+ 1.7	24	5,000	20	180	140
Potatoes, sweet	1.8	26.9	0.7	1.0	1.1	.019	.045	7.7	1.5	+ 6.7	121	4,200	100	33	70
Potatoes, white	2.0	18.7	0.1	0.4	1.0	.014	.058	9.1	1.7	+ 7.0	84	40	150	28	50
Pumpkins	1.2	6.0	0.2	1.3	0.8	.023	.059	9.3	0.3	+ 1.5	31	2,500	50	10	45
Radishes	1.2	3.5	0.1	0.7	1.0	.021	.029	8.3	1.6	+ 2.9	20	0	90	26	35
Rhubarb	0.5	3.1	0.1	0.7	0.7	.044	.031	5.6	0.5	+ 8.5	15	100	24	15	...
Rutabagas	1.1	7.6	0.1	1.3	0.8	.074	.056	3.6	1.5	+ 8.5	36	25	75	30	100
Salsify (oyster plant)	3.5	13.7	1.0	1.8	0.9	.060	.053	16.0	2.9	+ 2.9	78	...	..	7	...
Sauerkraut	1.3	3.5	0.2	1.4	2.4	.040	.025	4.0	0.4	+ 5.7	21	20	24	0–10	...
Spinach	2.3	2.6	0.3	0.6	1.5	.067	.068	25.5	1.2	+27.0	22	8,400	100	75	400
Squash, summer	0.6	3.4	0.1	0.5	0.4	.018	.015	3.5	0.8	+ 1.0	17	1,000	42	23	80
Squash, winter	1.5	7.4	0.3	1.4	0.8	.019	.015	5.5	0.4	+ 2.6	38	7,000	48	3	80
Taro	2.0	20.7	0.2	0.8	1.2	.039	.049	39.0	....	+18.1	93	.....	..	...	...
Tomatoes	1.0	3.4	0.3	0.6	0.6	.011	.026	4.4	0.7	+ 5.6	20	2,000	80	27	90
Turnips	1.1	6.0	0.2	1.1	0.7	.064	.046	5.2	0.9	+ 2.7	30	15	60	43	50
Turnip greens	2.9	4.2	0.4	1.2	1.8	.216	.075	34.8	0.9	+ 2.3	32	16,000	140	120	370
Water cress	1.7	2.8	0.3	0.5	1.1	.157	.046	29.7	0.4	+12.0	21	4,000	120	60	250

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* Values mostly from Nutritional Charts, 1942, H. J. Heinz Co., by permission.

† Vitamin A is expressed in International units, vitamin B_1 and B_2 in micrograms and vitamin C in milligrams per 100 grams or ml. of food.

Parsnips. Most parsnips go to the market without passing through cooler storage. When they do have to be stored for some time, a humidity of 95% and a temperature of 32° F. to 34° F. are desirable.

Peas. Like snap beans, peas appear in many varieties. Some shelled peas are stored but most of the crop comes to the cold-storage warehouse in the pod. Peas should be cooled very soon after picking if they are to go into storage. If left in baskets or piles in the warm condition, they heat up rapidly by enzyme action. This should be prevented, since it represents fermentation starting in the peas. The storage rooms should be held at 32° F. and 90% relative humidity. The baskets or hampers should be arranged to allow plenty of air to circulate around each basket.

Potatoes. Irish potatoes require ample ventilation if they are to be stored successfully. If they come in to the cooler in bags, the individual piles should not be more than 4 to 5 ft. high. If room storage space requires that better use be made of the room, secondary racks should be provided for the second flight of sacks in the upper part of the storage room.

Irish potatoes should not be stored at cold temperatures. Although they might keep longer when stored at 40° F., the resultant cooked potatoes taste better if stored at 50° F. Seed potatoes should be stored at 38° F. to 40° F. Storage of seed potatoes below 38° F. will affect the germination. A humidity of 90% is satisfactory for seed stock.

Sweet Potatoes. An unusually large portion of the sweet potatoes stored in northern storage houses are held at too low a temperature. There is too great a tendency to store sweet potatoes at the same temperatures as Irish potatoes. They are an entirely different vegetable. Sweet potatoes should be cured at a temperature of 85° F. for a period of two weeks. During this period they are held at 80% to 85% relative humidity. After this curing is complete, the sweet potatoes can be stored at 55° F. to 60° F. for three to four months.

When stored at low temperatures, sweet potatoes become very sweet and have an unnatural flavor. If sweet potatoes have been stored at too low a temperature and become excessively sweet, they can be partially reclaimed by changing them to a 70° F. room for a period of two to three weeks, then returning them to a 60° F. storage.

TABLE 15-6. KEEPING TIME OF PRODUCTS IN COLD STORAGE AND TEMPERATURES AT WHICH THEY BEGIN TO FREEZE

Commodity	Approximate Storage Life	Average Freezing Point, °F.
Apples	2-7 months	28.4
Artichokes		
Globe		29.1
Jerusalem	2-5 months	27.5
Asparagus	3-4 weeks	29.8
Avocados	1-2 months	27.2
Beans		
Green or snap	2-4 week	29.7
Lima	2-4 weeks	30.1
Beets, topped	1-3 months	26.9
Blackberries	7-10 days	28.9
Broccoli (Italian)	7-10 days	29.2
Cabbage	3-4 months	31.2
Carrots, topped	4-5 months	29.6
Cauliflower	2-3 weeks	30.1
Celery	2-4 months	29.7
Coconut		
Milk	1-2 months	30.4
Flesh	1-2 months	25.5
Corn (sweet)	1-2 months	29.0
Cranberries	1-3 months	27.3
Cucumbers	10-14 days	30.5
Dates		−4.1
Eggplants	10 days	30.4
Endive	2-3 weeks	30.9
Florists' stocks		
Fern (leaves)	2 weeks-4 months	23.6
Garlic	6-8 months	25.4
Grapefruit	6-8 weeks	28.4
Grapes		
European type	3-6 months	24.9
American type	3-9 weeks	27.5
Horseradish	10-12 months	26.4
Leeks	1-3 months	29.2
Lemons	1-4 months	28.1
Lettuce	2-3 weeks	31.2
Limes	6-8 weeks	29.3
Melons		
Watermelons	2-3 weeks	28.8
Muskmelons	7-10 days	28.5
Honeydew and Honeyball	2-4 weeks	28.8
Mushrooms (cultivated)	2-3 days	30.2
Nuts		
Pecans	8-12 months	19.6
English walnuts	8-12 months	20.0
Onions and onion sets	6-8 months	30.1
Parsnips	2-4 months	28.9
Peaches	2-4 weeks	29.4
Peas (green)	1-2 weeks	30.0
Peppers (sweet)	4-6 weeks	30.1
Pineapples		
Mature green	3-4 weeks	29.1
Ripe	2-4 weeks	29.9
Plums (including prunes)	3-8 weeks	28.0
Potatoes		28.9
Pumpkins	2-6 months	30.2
Quinces	2-3 months	28.1
Raspberries		
Black	7-10 days	28.8
Red	7-10 days	30.4
Rhubarb	2-3 weeks	28.4
Squash (winter)	2-6 months	29.3
Strawberries	7-10 days	29.9
Sweet potatoes	4-6 months	28.4
Tomatoes		
Ripe	7-10 days	30.4
Mature green	3-5 weeks	30.4
Turnips (including rutabagas)	4-5 months	30.5

Squash. Winter squash can be stored satisfactorily at the same room temperature and humidity as sweet potatoes. They should not be held at low temperatures.

Tomatoes. Tomatoes are not long keepers. Green tomatoes can be held for two to three weeks at 32° F. without appreciable ripening. They can then be ripened at 70° F. for immediate consumption. Firm, ripe tomatoes should be kept at 50° F. and 90% relative humidity. They can be kept safely for five to eight days. Firm, green tomatoes can be kept at 50° F. for three to four weeks and will ripen in storage.

ENGINEERS' INSPECTION OF COLD STORAGE PLANTS *

(a) Determine how many tons refrigeration could be saved or how many additional tons of ice could be produced if all suction or cold lines were insulated. The approximate heat transmission values are given herewith (Transmission in Btu per linear foot of pipe per degree temperature difference for bare pipe):

Steel Pipe Size, in.	*Btu per 24 hrs.*
1	19.5
1¼	24.1
1½	27.2
2	33.2
3	46.7
4	58.5
6	84.0

For example, a 1¼ in. pipe, 200 ft. long, carrying 15° brine with 85° surrounding temperature, will waste 241 tons refrigeration during a six-months' summer season. 241 ÷ 1.6 = 150 tons ice.

(b) Repair all small breaks or fractures in bitumastic or other finish coat with plastic cement. This will prevent the moisture from having easy access to inside of insulation.

(c) Determine possible costs and materials required to place any idle vaults in service. All storage space should be kept active.

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* Compiled mostly by R. A. O'Neil. Published by permission of Southwestern Ice Manufacturers Association.

Check List:	*Checked By*	*Date Checked*
(1) Inspect plant and vault buildings for safety......		
(2) Check for roof or flashing leaks, cracks in parapet or firewall coping and leaks around window and door frames..................		
(3) Examine steel sash for rusting and pitting behind glass. Coat with good rust preventative.. .		
(4) Inspect lighting and power wires for possible fire hazards.........................		
(5) Examine wall and ceiling insulation in ice vaults. If bond between corkboard or other board insulation and wall has broken, this can usually be repaired by installing buckstay on approximately 4-ft. centers..............		
(6) Check insulation around chutes and doors for ice-pick and other holes. Provide soft board for ice picks.........		
(7) Examine walls for structural cracks and fill these with seam filler or brine putty, being sure to fill entire depth of crack.........................		
(8) Replace all gaskets and hardware on doors and chutes that are defective. The hinges and latches should be properly adjusted and lubricated.. .		
(9) Inspect all pipe insulation including cold lines passing through walls. The cracks should be filled with seam filler and insulation painted once each year with odorless asphalt paint.		
(10) If meats or foods are stored in vault, make regular checks to see that rats and mice are not bedding in cork insulation..............		

FUR STORAGE

The large investment in furs within North America and the susceptibility to moth damage at high temperatures have made fur storage very popular. Although fumigation methods can be successfully used, it requires more skill to preserve furs successfully by the fumigation processes than it does by controlled refrigeration.

Furs may be kept in cold storage indefinitely without any accelerated deterioration other than that from ordinary aging. The storage room should be held at normal dry-climate relative humidity of 50% to 65%. High humidities encourage mold growths and exceedingly dry rooms cause deterioration of the hair and skin. Thus the control of the room at a relative humidity of 50% to 65% is very necessary.

The storage temperature for furs is 35° F. to 40° F. However, furs brought to storage should first be given a low-temperature treatment to kill the moths and larvae and destroy the eggs. If fur is stored for 24 hrs. at 0° F., the eggs of the moths will be completely destroyed. It will require approximately four days to accomplish the same result at 15° F. Experimental studies and practice have indicated that the best results can be obtained by putting the furs through a cycle of low and high temperatures. This cycle should be repeated three or four times during the first month of storage, then the furs should be held at 35° F. temperature and 50% to 65% relative humidity.

The cycle recommended to process the furs is two days at 50° F., followed by either two days at 10° F. or three days at 15° F. This is effective in the complete destruction of the eggs, larvae and moth life if it is repeated three or four times before bringing the room to the holding temperature of 35° F.

From the operational standpoint it is well to have the furs cleaned and a record made of the fur condition. A written record is much more reliable than a customer's memory relative to the condition of the fur when delivered to the storage warehouse.

SECTION XVI

FREEZER STORAGE

For cold storage the freezing-point temperature represents the limiting danger temperature for storing products without freezing. For freezer storage it should be understood that these values generally represent the temperatures at which the freezing process begins with these specified products. They give no indication of the temperature at which the product is completely frozen. For example, although an egg will begin to freeze at 29° F., the crystallization of the colloidal or water solution content of the egg will not be complete until the temperature of the egg has been lowered below 10° F.

Factors Affecting Foods in the Frozen State

Deterioration of foods during transportation and storage may be due to both physical and chemical agencies. Some physical changes are caused by mechanical damage, whereas others, such as loss of color and texture, are the secondary result of chemical changes. Deterioration due to chemical changes may be classified into three broad groups:

(1) Changes due to the action of microorganisms which live upon the food. Examples of this class are fermentation, molding, souring and putrefaction.

(2) Changes due to the action of enzymes which are naturally present in the food. Examples of this class are browning of the cut surfaces of many fruits and vegetables, and the development of "hay flavor" in dehydrated or frozen, unblanched vegetables.

(3) Chemical changes which are not due to microorganisms or enzymes. Of these, oxidation is the most important, although hydrolysis may also cause loss of flavor.

Examples of deterioration caused by oxidation are rancidity in fats, loss of flavor from spices which are exposed to air and the bleaching of natural coloring matters.

Although it is not intended to imply that microorganisms are chemicals, the changes which they produce in foods are exclusively of a chemical nature. Pasteur first demonstrated that sugar is converted to alcohol and carbon dioxide by yeast, but later Buchner showed that the same conversion is caused by an extract of yeast in which no living cells are present. It has since been shown that much of the change which microorganisms produce in food is caused by substances elaborated and excreted by the living cells. Although certain varieties of microorganisms will grow only within a very limited temperature range, it has been shown that in general the rate of growth decreases as the temperature drops and that this rate follows the law governing the rate of chemical reactions. Thus, it may be stated that the action of microorganisms is essentially chemical in every respect.

Enzyme action and chemical action follow the general law which relates the rate at which the action occurs and the absolute temperature thus:

$$\log r = A - \frac{B}{T} \quad \text{or} \quad r = 10^A \times \frac{1}{10^{\frac{B}{T}}}$$

in which r is the rate at which the action occurs; A and B are constants for the specific action; and T is the absolute temperature. It may be stated that the rate at which most chemical reactions occur is approximately halved by a decrease of 18° F., but some molds continue to grow until the temperature reaches 10° F. Enzyme action virtually ceases at −20° F., whereas a temperature of −40° F. reduces the rate of oxidation to such a low figure that exceedingly long periods would be required to develop a noticeable rancidity in fat.

Thus, it is apparent that the temperature necessary to insure satisfactory preservation of a particular food is dependent upon the presence or absence of microorganisms and upon the types and amounts of enzymes and oxidizable substances present. In a food which contains no enzymes or substances which are easily oxidized, a temperature of 10° F. will prevent the development of microorganisms and assure ample protection against deterioration. However, nearly all perishable foodstuffs contain both enzymes and oxidizable substances; hence, it is necessary to select storage conditions which minimize damage. It has been learned that frozen vegetables, stored at 0° F., rapidly develop unpleasant odors and flavors and also lose color to such an extent that they become unmarketable. However, blanching the material before it is frozen inactivates the enzymes and allows the product to be stored at 0° F. without deterioration. Sugar inhibits the action of the enzymes which cause the familiar browning of sliced apples, peaches and other fruits; thus, it has become an almost universal practice to pack frozen fruits with sugar. Sulphur dioxide and ascorbic acid (vitamin C) also help to prevent the undesirable browning and are rather widely employed for this purpose. Oxidation may be minimized by enclosing foods in protective coatings or packages which exclude atmospheric oxygen. One of the earliest examples of such a protective coating is the iceglaze which has been extensively employed to prevent oxidation of the body oil of fatty fish in frozen storage.

These methods which supplement the preserving effect of low temperatures are of very great value in the storage of frozen foods. They have the effect of making a moderate temperature as efficacious as much lower temperatures alone. Further, their use assures some protection in case the storage temperature is temporarily raised or when the product is defrosted for using.

LATENT HEAT VALUES

For all practical purposes the latent heat of foods can be computed by multiplying the percentage of water in the commodity by 143.4, the latent heat of fusion of the water in the commodity. The experimental values determined in the University of Tennessee Engineering Experiment Station * will be found interesting. The proximity of the experimental values to the values that would be found by multiplying the percentage of water within the commodity by 143.4 is evidence of the practical reliability of the computation method. Probably the computed values are the more nearly correct as experimental error is eliminated. This relationship was discovered by W. R. Woolrich in 1927 and was later checked in collaboration by Cooper, Scates, Smith and Tucker. In all, the latent heats of twenty-seven products were experimentally determined by a separate series of check determinations. The materials investigated included fruits, vegetables, meats, fish

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* Woolrich, Cooper, Scates and Tucker, "The Latent Heat of Foodstuffs," *Bulletin No. 11*, Eng. Exp. Station, Univ. of Tennessee.

and dairy products. In every instance the determined latent heat corresponded to the value obtained by the Woolrich equation, or

$$L_f = 143.4P,$$

where L_f = the latent heat of fusion of the product in Btu per pound and P = percentage by weight of the water in the foodstuff.

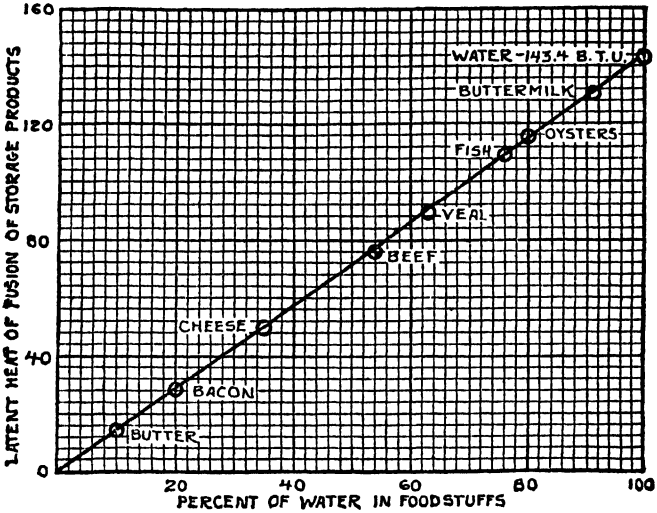

FIG. 16–1. Relation of the latent heats of fusion of cold storage products to the water content of the product stored.

On no occasion did any other constituent except the water affect the latent heat in value. Experiments were tried with materials that have a high fat content, but no percentage of fat affected the latent heat result. Other investigations were made with materials of a high salt and sugar content, but these had no effect upon the latent heat.

The studies led to a series of determinations of the latent heats of fusion of fish, in which it was expected that some of the crystal formations of the acids present in fish would affect the result, but in no case was a foodstuff found that varied from the experimental law given above.

These researches also led into an investigation of freezing ranges. The methods used in determining the latent heat can also be applied in determining the freezing range of foods to be frozen.

Table 16–1. Latent Heats and Per Cents of Water and Solids of Fruits

Fruits	% Solids	% Water	Latent Heat, Btu
Apples	15.6	84.4	121.0
Apricots	14.0	86.0	123.5
Avocados	24.6	75.4	108.0
Bananas	24.4	75.6	108.5
Blackberries	14.2	85.8	122.5
Blueberries	16.3	83.7	120.0
Cherries	16.4	83.6	120.0
Cranberries	12.4	87.6	125.5
Currants	14.7	85.3	122.5
Dates, dried	78.2	21.8	31.0
Figs, dried	73.6	26.4	42.0
Gooseberries	11.3	88.7	127.0
Grapefruit	10.8	89.2	128.0
Grapes	17.7	82.3	118.0
Guavas	18.5	81.5	117.0
Lemons	10.2	89.8	128.5
Limes	9.8	91.2	131.0
Loganberries	16.6	83.4	119.5
Mangos	17.2	82.8	118.5
Melons			
Cantaloupe	5.4	94.6	136.0
Honeydew	8.8	91.2	131.0
Muskmelon	6.7	93.3	134.0
Watermelon	7.6	92.4	132.5
Nectarines	16.6	83.4	119.5
Olives, green	19.0	81.0	116.0
Oranges	12.3	87.7	125.5
Papayas	10.7	89.3	128.0
Peaches	12.6	87.4	125.0
Pears	16.9	83.1	119.0
Persimmons	34.9	65.1	87.0
Pineapples	14.3	85.7	122.5
Plums	13.8	86.2	123.5
Pomegranates	18.5	81.5	117.0
Prunes, dried	73.9	26.1	37.5
Quinces	14.3	85.7	122.5
Raisins	76.0	24.0	34.5
Raspberries, black	18.7	81.3	116.5
Raspberries, red	16.1	83.9	120.5
Strawberries	9.5	90.5	130.0
Tangerines	12.0	88.0	126.0

TABLE 16-2. LATENT HEATS AND PER CENTS OF WATER AND SOLIDS IN VEGETABLES

Vegetables	% Solids	% Water	Latent Heat, Btu
Artichokes	15.2	84.8	121.5
Asparagus	6.3	93.7	134.0
Beans, green	10.3	89.7	128.5
Beans, lima, green	31.8	68.2	91.0
Beets	11.3	88.7	127.0
Beet greens	7.9	92.1	132.0
Broccoli	9.0	91.0	130.5
Brussels sprouts	13.8	96.2	123.5
Cabbage	6.9	93.1	133.5
Carrots	10.8	89.2	128.0
Cauliflower	7.5	92.5	132.5
Celery	5.2	94.8	136.0
Chard, leaves	7.8	92.2	132.0
Collards	11.7	88.3	126.5
Corn, yellow (green)	25.4	74.6	107.0
Cucumbers	3.5	96.5	138.0
Dandelion greens	12.2	87.8	125.5
Eggplant	6.8	93.2	133.5
Endive	5.8	94.2	135.0
Escarole (chicory)	4.8	95.2	136.0
Garlic	24.6	75.4	107.5
Horseradish	24.8	75.2	107.5
Kale	11.7	88.3	126.5
Kohlrabi	8.9	91.1	130.5
Lambsquarters	12.8	87.4	125.0
Leeks	10.8	89.2	127.5
Lettuce	4.3	95.7	137.0
Marrow	4.6	95.4	136.5
Mushrooms	8.1	91.9	131.5
Mustard greens	6.6	93.4	134.0
Okra	8.5	91.5	131.0
Onions	11.9	88.1	126.5
Parsley	13.7	86.3	123.5
Parsnips	20.2	79.8	114.5
Peas, green	24.8	75.2	107.5
Peppers, green	7.1	92.9	133.0
Potatoes, sweet	30.4	69.6	92.5
Potatoes, white	21.2	78.8	112.5
Pumpkins	8.7	91.3	131.0
Radishes	5.5	94.5	135.5
Rhubarb	4.4	95.6	137.0
Rutabagas	10.1	89.9	128.0
Salsify	20.0	80.0	114.5
Spinach	5.8	94.2	135.0
Squash, summer	4.6	95.4	137.0
Squash, winter	10.6	89.4	127.5
Tomatoes	5.3	94.7	135.5
Turnips	8.4	91.6	131.5
Turnip greens	8.7	91.3	131.0
Water cress	5.3	94.7	135.5

FREEZING POINTS IN THE FREEZING PROCESS

Freezing points as such do not exist with most solutions and food products. The freezing points as given are the temperatures at which freezing of the product begins. Whereas with water there is the definite freezing point of 32° F., with sugar, salt, and colloidal solutions the freezing process may continue to a temperature far below 0° F.

Experimental determinations by Short have been presented in a series of experimental values for meats, fish, fruits and vegetables, and are given in the following charts.

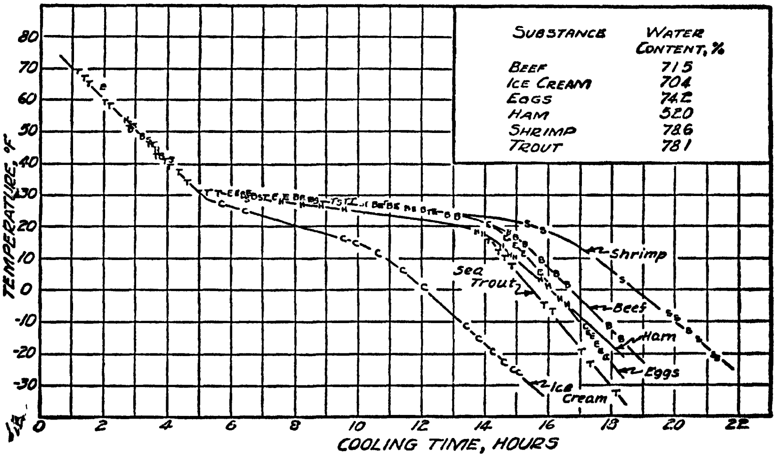

FIG. 16–2. The freezing of meats, fish, eggs and ice cream.

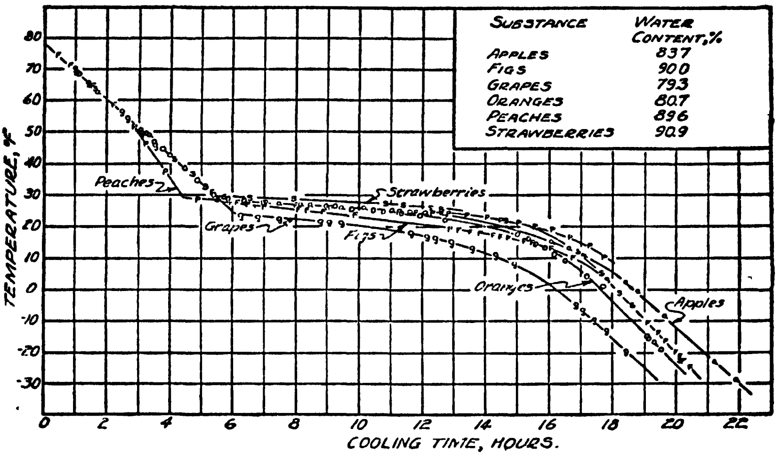

FIG. 16–3. The freezing range of fruits.

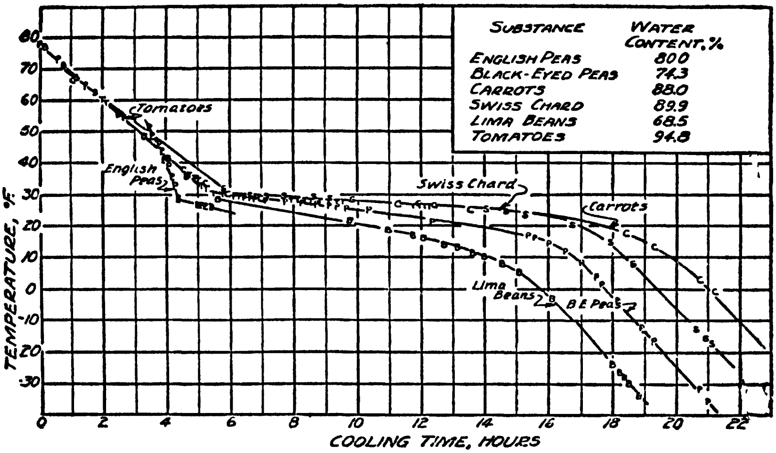

FIG. 16–4. The freezing range of vegetables.

TEMPERATURES AT WHICH QUICK-FROZEN FOODS SHOULD BE STORED

Much of the value obtained in the quick freezing of foods is often lost by failure of the storage house to keep the frozen product at a low enough temperature and to maintain this temperature relatively free from variation. Varying the holding temperature of many quick-frozen foods is fully as harmful as storing them at too high a temperature.

TABLE 16-3. STORAGE TEMPERATURES FOR QUICK-FROZEN FOODS

Name of Product	Storage Temperature, °F.
Cream	−10
Eggs	0
Fish	−10
Fruits	0
Ice cream	−20
Seafood, general	− 5
Meat	0
Poultry	− 5
Vegetables	0

TABLE 16-4. FROZEN FRUITS IN COLD STORAGE IN THE U. S. JAN. 1, 1945

Commodity	Pounds
Apples	34,154,000
Blackberries	11,272,000
Cherries	34,447,000
Young, Logan, Boysen, etc.	8,997,000
Raspberries	13,086,000
Strawberries	19,504,000
Grapes	19,414,000
Plums and prunes	14,240,000
Peaches	30,020,000
Fruit juices and purées	15,740,000
All other fruits	68,218,000
Total	269,092,000

TABLE 16–5. POUNDS OF FROZEN FRUIT IN STORAGE IN THE U. S. ON DATE INDICATED

Month	1944	5-Yr. Average
Jan. 1	226,784,000	152,526,000
Feb. 1	208,582,000	138,489,000
Mar. 1	186,844,000	122,069,000
Apr. 1	161,221,000	104,928,000
May 1	130,855,000	86,988,000
June 1	116,111,000	92,102,000
July 1	132,513,000	121,439,000
Aug. 1	208,097,000	166,281,000
Sept. 1	246,939,000	182,867,000
Oct. 1	297,885,000	193,091,000
Nov. 1	300,922,000	194,263,000
Dec. 1	294,309,000	185,547,000

TABLE 16–6. FROZEN VEGETABLES IN COLD STORAGE IN THE U. S. JAN. 1, 1945

Commodity	Pounds
Asparagus	6,423,000
Beans, lima	12,301,000
Beans, snap	16,221,000
Broccoli	4,511,000
Cauliflower	2,930,000
Corn, sweet	19,331,000
Peas, green	45,859,000
Spinach	16,973,000
Brussels sprouts	3,765,000
Pumpkin and squash	8,624,000
Baked beans	3,869,000
Vegetable purées	781,000
All other vegetables	26,321,000
Total	167,909,000

TABLE 16–7. POUNDS OF FROZEN VEGETABLES IN STORAGE IN THE U. S. ON DATE INDICATED

Month	1944	5-Yr. Average
Jan. 1	185,456,000	82,547,000
Feb. 1	170,108,000	75,066,000
Mar. 1	153,762,000	65,670,000
Apr. 1	129,767,000	58,995,000
May 1	105,417,000	52,141,000
June 1	98,576,000	48,818,000
July 1	115,236,000	60,654,000
Aug. 1	135,059,000	79,336,000
Sept. 1	164,383,000	94,108,000
Oct. 1	178,017,000	108,556,000
Nov. 1	187,437,000	113,572,000
Dec. 1	183,447,000	114,397,000

TABLE 16–8. POUNDS OF FROZEN EGGS IN STORAGE IN THE U. S. ON DATE INDICATED

Month	1944	5-Yr. Average
Jan. 1	101,701,000	77,399,000
Feb. 1	81,677,000	59,299,000
Mar. 1	99,437,000	51,612,000
Apr. 1	148,420,000	74,934,000
May 1	218,077,000	119,943,000
June 1	293,183,000	171,823,000
July 1	354,900,000	214,338,000
Aug. 1	387,182,000	227,220,000
Sept. 1	371,490,000	218,246,000
Oct. 1	332,415,000	194,352,000
Nov. 1	278,628,000	158,507,000
Dec. 1	219,798,000	121,463,000

TABLE 16-9. POUNDS OF FROZEN BEEF, PORK, LAMB AND MUTTON IN STORAGE IN THE U. S. ON DATE INDICATED

Month	1944	5-Yr. Average
Jan. 1	908,367,000	706,916,000
Feb. 1	1,064,902,000	814,922,000
Mar. 1	1,252,551,000	840,745,000
Apr. 1	1,246,813,000	813,562,000
May 1	1,215,501,000	777,771,000
June 1	1,163,799,000	758,407,000
July 1	1,105,654,000	720,558,000
Aug. 1	906,598,000	676,060,000
Sept. 1	740,299,000	671,917,000
Oct. 1	575,558,000	478,828,000
Nov. 1	529,247,000	466,056,000
Dec. 1	528,348,000	560,938,000

TABLE 16-10. POUNDS OF FISH FROZEN IN THE U. S. DURING MONTH INDICATED

Month	1944	5-Yr. Average
Dec. 1	25,102,521	18,607,000
Jan. 1	15,031,136	7,467,000
Feb. 1	8,480,876	6,728,000
Mar. 1	8,836,450	6,007,000
Apr. 1	11,262,296	7,801,000
May 1	17,646,780	15,621,000
June 1	32,269,410	23,464,000
July 1	36,161,857	29,718,000
Aug. 1	38,909,399	30,251,000
Sept. 1	32,966,670	27,165,000
Oct. 1	28,481,018	23,646,000
Nov. 1	23,739,798	22,257,000

TABLE 16-11. POUNDS OF FROZEN FISH IN STORAGE IN THE U. S. ON DATE INDICATED

Month	1944	5-Yr. Average
Dec. 1	107,415,515	101,280,000
Jan. 1	98,888,105	88,153,000
Feb. 1	85,858,651	70,792,000
Mar. 1	68,190,857	50,180,000
Apr. 1	52,786,460	35,845,000
May 1	51,567,584	37,469,000
June 1	29,291,802	49,144,000
July 1	89,987,019	67,222,000
Aug. 1	109,088,513	83,130,000
Sept. 1	123,698,620	94,089,000
Oct. 1	131,617,975	99,639,000
Nov. 1	130,857,568	102,242,000

SECTION XVII

QUICK FREEZING OF FOODS

The term "quick-frozen" as applied to food is very elastic and much abused. Many cases are on record of products which have been frozen by methods that required as much as a week for complete solidification, yet they were labeled "quick-frozen." Such loose usage does not induce increased public confidence and acceptance. Too often the practice represents an attempt by some food processor to offer his cold-pack product under a classification that has the highest customer appeal in the food market. A previously proposed definition states: "Quick freezing is freezing at a rate sufficiently fast that there is no appreciable change in the physical or chemical properties of the product during the entire cycle of freezing and subsequent thawing."

The commercial food processor has little control over the method used to defrost his product; he can only print directions on the package and hope the consumer will follow instructions. But he does have control over the method of freezing and should employ the process which produces the minimum of change during this portion of the cycle.

More or less modification of any food may occur when it is frozen. Usually these changes are not apparent until the product has been thawed and in many cases further undesirable changes, due largely to enzyme action, may occur after defrosting is completed.

Theories on Cause of Food Damage by Slow Freezing. Several theories have been advanced to account for the effect of slow freezing. These include the cell-puncture theory, the bursting of the food cells by internal-osmotic-pressure theory, and the theory of the irreversible precipitation of colloidal constituents. Each of these will be discussed in order.

Cell-puncture Theory. Perhaps the most widespread and persistent hypothesis is the cell-rupture theory, which holds that the cell walls are punctured by growing ice crystals and that upon thawing the cell contents leak out through these minute ruptures.

It is also held that, if the size of the ice crystals can be maintained less than the cell dimensions by rapid chilling, no puncturing with its consequent leakage will occur.

It should be borne in mind that foods are not composed of rigid inelastic cells. The walls are resilient and will permit considerable expansion before rupture occurs. Heat is removed from only one side of the cell so that expansion may occur on the opposite unfrozen side.

Microscopic observations conducted by the authors have revealed that, even when freezing is exceedingly fast,the smallest ice crystals are much larger than individual cells. Many cells are contained in one crystal instead of vice versa. The crystal lattice both inside the cell and in the intercellular spaces is continuous. No tearing or shearing of cell walls has been observed. The permeability of cell walls to water vapor or liquid is well established. This is merely another method of stating that water in the vapor or liquid state is continuous through the membrane. There is no reason to believe that attainment of the solid state interrupts this continuity.

In our investigations the technique which the mineralogist employs to prepare and examine thin sections of brittle materials has been adapted to frozen food. One side of the frozen specimen is cut to a plane surface which is cemented to a chilled microscope slide. The cemented specimen is now cut away to leave a thin section upon the slide. No distortion of the section to be examined occurs; and, since the entire operation is conducted in a refrigerated room using tools and apparatus which have been chilled to room temperature, the most delicate structure is completely unaltered. The prepared section may be protected against dehydration by a drop of chilled ice-machine oil and a cover glass.

A variation of this method consists of cutting a plane surface upon the unfrozen specimen, pressing the surface upon a clean microscope slide, and freezing by any desired method. The excess frozen material is then cut away, leaving a thin section adhering to the glass.

Examination of the section is accomplished by means of a petrological microscope which has a quarter-wave plate inserted between the crossed Nicol prisms. The illumination is supplied by a standard microscope lamp mounted at a distance and equipped with a filter to avoid heating the specimen under examination. The entire examination is conducted in a refrigerated room and every precaution is taken to prevent any change in the temperature of the specimen. Under these conditions, the product has the characteristics of a geological specimen and its crystalline structure can be so analyzed.

The field of the microscope and all isotropic substances are monochromatic, while ice crystals (which are anisotropic) present contrasting interference colors which are dependent upon the orientation of the crystal axes. The boundary of each crystal is clearly defined by the sharp color change and by the extinction which is successively observed in each crystal as the microscope stage is rotated. Cell walls and unfrozen portions are isotropic and exhibit no extinction or interference color.

Osmotic-damage Theory. Petersen proposed that damage to foods during freezing is due to the following mechanism: "What crystallizes first in each cell is pure water. That leaves the remainder of the juice in the cell more concentrated. The resultant increase in osmotic pressure tends to draw water from the next adjoining unfrozen cell. The water coming into the partly unfrozen cell has a tendency to build onto the crystals between the cells when the rate of freezing is so slow that the system approaches equilibrium." It also accounts for the occurence of collapsed cells contiguous to large ice masses in slowly frozen foods. However, this theory does not explain the damage which occurs in quick freezing when heat transfer so greatly exceeds diffusional rates at low temperatures that thermal equilibrium is attained before appreciable osmosis can occur.

Irreversible-colloidal-change Theory. Almost without exception perishable foods are colloidal systems in which the external or dispersing phase is an aqueous solution. This has led some investigators to the belief that alteration of the colloidal structure is responsible for changes during freezing, storage, and thawing. Although there are many factors which affect the stability of colloids, it is probable that only three concern the food processor:

(1) The lowering of temperature (distinct from the freezing effect) renders many colloidal dispersions unstable. Examples are the formation of gels from agar, soap, and starch hydrosols. This phenomenon is often followed by syneresis, that is, shrinking of the gel and exudation of fluid.

(2) Chemical changes which occur during frozen storage are irreversible. Many of them are due to enzyme action. The rapid deterioration of frozen unblanched vegetables is well known.

The "rusting" of oily fish (oxidation of the fat) is very familiar. It is probable that some of the loss of flavor from stored frozen foods may be traced to hydrolysis of esters and oxidation of unsaturated odorous components.

(3) Freezing causes concentration by removing liquid water from the external phase. Mere concentration, by decreasing the distance between dispersed particles may bring about critical instability.

Freezing may also effect sufficient concentration of electrolytes to cause "salting out" of hydrophilic colloids. While such precipitation is often reversible, long storage in this state may result in an irreversible precipitate. Bancroft, Weiser and Milligan and Foote and Saxton note that colloidal precipitates lose reversibility when allowed to age. Plank, Ehrenbaum, and Reuter state that upon thawing haddock within 24 hrs. after freezing, the flesh is gelatinous and there is no exudation of juices. This texture slowly changes when the frozen material is stored and after 149 days is replaced by a fibrous structure which loses juices rapidly when thawed. H. F. Taylor notes that slow-frozen haddock begins to lose juice when defrosted immediately after freezing, whereas the quick-frozen product does not; but after a few days in storage, the quick-frozen product will lose juices when thawed.

It is significant that the colloids which may be slowly frozen and thawed without damage are those which are not easily precipitated by electrolytes or which are free from electrolyte. Hardy and Moran describe the reversible freezing and thawing of gelatin gels. Egg albumen is commercially frozen upon a large scale without serious injury and the investigations of Kinoshita and Thoennes show that agar gels are reversible. It is well known that these colloids are not readily precipitated by salts of the alkalies, calcium, or magnesium.

Moran notes that hen eggs maintain normal consistency when frozen in liquid air and rapidly thawed in mercury at 30° C. (86° F.). He has shown that colloidal changes in eggs occur between −6° C. (21° F.) and an undetermined lower temperature, and suggests that lipins, which dissolve at critical electrolyte concentration, are irreversibly precipitated when the concentration is decreased by thawing. Only negligible damage will occur, if exposure to the temperature range at which these critical concentrations exist is made very short. In this case thawing and freezing rates are of equal importance.

Living leaf tissues have been frozen in liquid air and thawed both slowly and rapidly by Luyet. All slowly thawed samples were dead but many cells in the quickly thawed material were still living.

Artificial colloids, cheese, and eggs have no cellular structure to be damaged by mechanical rupture or by osmosis, yet they may be irreversibly altered by certain freezing technique. It seems questionable that continuous crystal growth, accompanied by progressive mechanical damage, could occur in frozen food which is stored at constant temperature over a long period of time. The deterioration of frozen foods in storage which has been reported by several investigators is probably due to colloidal changes. It is also hard to conceive that mechanical breakage could occur during either slow or quick thawing. The redistribution of water by osmosis requires much time which is not available during quick thawing. Chemical or colloidal phenomena only can account for these changes.

An Appraisal of the Theories of Freezing Damage. The freezing-damage theories might be appraised as follows:

Mechanical damage to cellular structures might be caused by ice crystals, especially for some classes of product. When this occurs, there is an internal shredding of the product, caused by growing crystals. The resultant damage is a function of the crystal size and freezing time.

Osmotic injury to cellular structure is possible but probably plays a minor role in the destruction caused by freezing. Water diffuses from unfrozen cells to the faces of growing ice crystals at a very slow rate. The action is irreversible when thawing occurs and might cause internal rupture.

Irreversible changes in the colloid system appear to be the principal cause for slow-freezing damage. Primary or secondary effects of low temperature cause irreversible precipitation of many colloids. This action is independent of cellular structure and explains the effect of freezing upon foods which do not consist of cells. The theory also accounts for the severe damage to some foods and the negligible damage to others when identical freezing technique is employed.

Rapid Freezing Rates Not Essential to All Footstuffs. Many have a mistaken idea that very rapid freezing is equally desirable for all perishable foods that require preservation by cold. The need of rapid freezing is much more pronounced for some perishables than for others. Furthermore, the colloidal composition of some products is such that even slow freezing affects the structure but slightly.

With most foods that are to be cooked as soon as defrosted, slow freezing is as satisfactory as quick freezing. In the case of meats, slow freezing may even have a tenderizing effect. Furthermore, any leakage of the meat subsequent to defrosting merely results in increased pan juices.

Vegetables with a high starch content display a much different response to the freezing treatment from leafy types that may exceed 90% of water by actual weight. Well-ripened berries and fruits with a high sugar content present a very different problem from acid and near-ripe fruit products.

Variations in Freezing Ranges of Foods to Be Frozen. The freezing point of any food product is that point at which freezing begins. An equally important physical factor in freezing is the temperature at which all of the free water of the product is completely crystallized. The temperature difference from the "freezing point" to temperature of the complete crystallization is considered the freezing range.

To assure a minimum of oxidation and thus reduce decomposition of a frozen food in storage, it is very desirable that crystallization of the water content be complete. The freezing and holding temperatures should be below the freezing range for successful freezing and subsequent storage.

Experiments by the authors indicate that the best commercial results will be obtained when the freezing and holding temperatures are held uniformly just below the freezing range of the product frozen.

The freezing ranges of foodstuffs vary widely, and freezing and holding temperatures that are quite satisfactory for one product may not be applicable to other products.

Supercooling Phenomena in Freezing Collodial Foods. Supercooling of colloidal systems and of food has often been described in the literature, but its applications seem to have been overlooked by food researchers. The term "supercooled" is applied to a system which has been cooled to a temperature below its true freezing point without the formation of a solid phase. It is a thermodynamically unstable state and tends to revert to the stable condition with the liberation of energy. The change may be hastened by mechanical shock or by "seeding," that is, by introduction of particles of the stable phases. Supercooling is frequently observed in liquids of high viscosity and in colloidal systems. Since most foods fall into one or both of these classifications, the phenomenon is frequently encountered in freezing-preservation technique.

R. Brooks Taylor has reported that strawberries immersed in sugar solutions held at 15° F. do not freeze, but that diffusion occurs until equilibrium is attained between the syrup and berry juices. He further states that syrup temperatures below 10° F. are necessary to secure freezing under these conditions. This is clearly a case of supercooling, since the true initial freezing point of strawberries is approximately 29.9° F., and at a temperature of 15° F. about 50% of the water content should be in the solid phase.

Experiments have shown that supercooling is largely prevented by "seeding" the external surface of the food with ice particles when the true freezing point is reached. Any food may be frozen at any temperature below its true freezing point if this technique is employed.

Supercooling in itself is no disadvantage for food preservation. Moran reports that fresh hen eggs, which have a true freezing point of −0.6° C. (31° F.), have been supercooled to −11° C. (12° F.), held for 24 hrs., and then warmed to room temperature without change; but if freezing occurs below −6° C. (21° F.), the character of the thawed egg is changed. If foods could be supercooled to 0° F. and held indefinitely in this state, excellent preservation would be possible. At this temperature microorganisms are inactive, enzyme and chemical changes are slow, and the supercooled colloid structure is largely unchanged. Unfortunately, solid phases appear in many foods at high temperatures. In this case supercooling is a real disadvantage.

The three principal operating disadvantages of supercooling are:

(1) The over-all rate of heat transfer is reduced, necessitating a longer freezing period and reducing the capacity of the freezing machine.

(2) When heat transfer is accomplished by means of a chilled fluid, soluble components of the food diffuse into the fluid until the food surface is essentially solidified. Some of these components possess flavors and colors which might be undesirable in subsequently frozen batches. Juices dilute the freezing medium and

make it necessary to reconcentrate periodically and to remove accumulated gummy substances.

(3) Unnecessary damage is caused by freezing a colloidal system after severe supercooling. Callow has shown that the linear rate of ice formation is 1680 cm. per hr. in 1% gelatin gels which are seeded after supercooling. This is enormously in excess of any possible rate of advance of a uniformly frozen boundary. It may be shown that approximately 400,000 Btu per sq. ft. per hr. must be removed from food to freeze uniformly a slab at this rate. This means that when the phase change is inaugurated in chilled food, filaments of frozen material form in the supercooled zone and rapidly extend far beyond the uniform boundary. Latent heat of fusion is released, and the concentration of the solutes in the external colloid phase is increased. This combination of increased temperature and electrolyte concentration accounts for the precipitation of many colloids in the unfrozen space between the filaments.

EXISTING COMMERCIALLY USED QUICK-FREEZING PROCESSES AND FREEZING EQUIPMENT

The principal agents that have been developed for the quick freezing of foods are:

(1) Cold-air Blast. Cold-air currents are sometimes used in insulated tunnels through which the product to be frozen is progressively advanced at a rate sufficiently slow to permit the solidification of the product before it emerges from the tunnel. In other designs the tunnel is equipped with a rotating cylinder slightly inclined and operated quite like a gravel screen. In air freezing the rate of heat transfer from product to still air is relatively low and the devices used to increase this rate are rapid movement of air, large temperature differentials between air and product, and keeping the surfaces of the product well exposed to the circulating air. Temperatures as low as −45° F. and air velocities of 5000 ft. per min. have been advocated. Cold-air-blast freezing is more acceptable for small articles or products than for large pieces. Because of the much higher ratio of exposed surface on small specimens, it is more satisfactory for peas, spinach, and small berries. It is successfully used on meats where a high rate of freezing is not so essential.

Great care must be exercised in freezing some products by cold air to assure a low dehydration. If loss of weight is a vital factor in the freezing process, then cold-air freezing should be very closely controlled and a high humidity maintained.

Two-stage blast freezers have been proposed to minimize dehydration, by maintaining small temperature differentials between the product and the circulating chilled air. Thus when the food has been properly prechilled in the first stage, it is transferred to the second stage where contact with much colder air completes the freezing.

Much of the quick freezing by cold air is no different from the sharp-freezing practice that existed many years before quick freezing was introduced. In cold storage the use of air at very low temperature is usually classed as "sharp freezing." However, where the cross section of the product is small or the ratio of exposed surface to weight is large, cold-air-blast freezing can be rapid enough to qualify properly as quick freezing. Large quantities of fish are frozen by the cold-air method, then sprayed with ice water which immediately solidifies to a protecting ice glaze.

(2) Metal Plates and Metal Pressure Surfaces. Metal plates have been used successfully for quick freezing since the inception of the industry. The fact that metal has a very high rate of heat transfer, that it can be used with the refrigerant on one side and the product to be frozen on the other side, and that plates are part of the conveying devices, has made these processes very satisfactory and attractive to inventors.

Many devices have been described in which a loose product, such as berries, peas, and lima beans, are moved by conveyers while in contact with chilled metal surfaces. One type consists of a refrigerant-jacketed horizontal metal tube through which material and air are carried by a screw conveyer. Another type employs an inclined chilled tube, having an internal screw thread, through which loose product and air are conveyed by rotation of the tube. Yet another variation employs horizontal metal plates, over which the food is pushed by scraper blades.

In some equipment a single-plate system is used, the refrigerant side being chilled by direct expansion or by brine, either sprayed or allowed to flow over the surfaces. In its very simplest form the plates may be stationary and the foodstuff presses onto the single plates. In other designs the plates may be movable and pressed against the product to be frozen.

In the more highly developed systems, a double-plate design is often employed. For example, in one system, the products to be frozen are placed on a flexible conveyer belt which carries the product parallel with and against a second refrigerated metal belt. As the product, which is usually packaged, is carried between these two metal surfaces, it is frozen to the desired degree by controlling the speed on the belts.

In another system, the two refrigerated plates are the upper and lower refrigerated platens of a press. The package is placed between these pressure plates, the press set into operation, and the freezing occurs with the pressure plates holding the package firmly until frozen.

The principal disadvantage of most plate freezing processes is the need to place the product in a package before freezing. Most packaging material is of an insulating nature. Thus the advantage gained in rapid heat transfer through the metal is largely lost in the insulating properties of the package.

One large processor has recently developed the double-plate system to operate without the disadvantage of having the package-insulating material between the product and the plates. The freezing is done by direct contact of the product with the plates, then the product is quickly detached from the plates by a sudden momentary warming of the plates. The advantage of rapid heat transfer in freezing is expected to more than offset the loss due to the intermediate warming between freezing periods in the cycle.

(3) Cans. After considerable research some commercial development has been successful in quick freezing in cans. The chilled product is sterilized, canned, and sealed, then submerged in a low-temperature brine for a sufficient period to freeze to a low temperature. A high heat transfer is obtained by rapid circulation of the brine over the cans, by movement of the cans and by agitation of the product in the cans. One interesting method of freezing foods in hermetically sealed packages utilizes immersion in a bath of evaporating liquid propane. Another method proposes that containers which are not wetted or affected by mercury are to be immersed in a chilled bath of that metal. For certain products, this is satisfactory, but there are many to which such a process cannot apply.

(4) Liquids for Immersion and Spraying. Immersion and spraying systems were recommended nearly a century ago. A large number of liquids have been proposed for freezing foods by direct contact. Aqueous solutions containing common salt are suggested for treating meat, fish, and vegetables. Variations include the incorporation of ethyl alcohol, glycerol, potassium nitrate, and sugars. One composition of water, salt, and sugar is said to possess a neutral flavor. Solutions containing water, glycerol, and ethyl alcohol have been proposed. Sugar syrups and solutions containing invert sugar and other soluble carbohydrates have been successfully used to freeze fruits. Concentrated fruit juices or juice fortified with added sugars have also been proposed for fruit freezing. Poultry has been frozen by submerging in a bath of evaporating liquid carbon dioxide, recovering the gas, and reliquefying the carbon dioxide. It has been suggested that fruit juices might be quick-frozen by admixture under pressure with liquid propane in such proportions that, when subjected to reduced pressure, the propane would be completely volatilized and removed from the frozen juice.

The merits of various immersion liquids have been widely discussed. It may be pointed out that some foods frozen by the older methods of direct contact with brine may retain an undesirable quantity of salt. Ethyl alcohol is very definitely objectionable to a large group of American buyers and in addition is so hedged about by governmental restrictions that its accepted use in a freezing fluid for foodstuffs seems unlikely. The market price of glycerol fluctuates widely, while at the present time it is a necessary raw material for the manufacture of vitally needed explosives. Sugar is a well-recognized food and also a very effective agent to inhibit the deteriorating effects of oxidation and enzyme action upon foods.

The fog-spray method was introduced in the United States by Zarotschenzeff. The products to be frozen are sprayed with atomized brine either in cartons or directly on the product. The liquid is collected, refrigerated, filtered, and recirculated by means of a pump. This system is very effective but has not had as wide an application in this country as it deserves.

The liquid-immersion method of freezing, described by Ferris and Taylor, using either a saline- or a sugar-immersion bath was reintroduced commercially by the research divisions of the Tennessee Valley Authority and has been found to be very satisfactory for berries, peaches, solid vegetables, and marine products. Their patents cover several features of immersion-freezing.

Freezing foodstuffs by direct contact with a chilled fluid has several advantages over other methods. Especially does it afford a high rate of heat transfer with a relatively small temperature differential. The resultant product is exceptionally good.

It was in this field of fluid-contact freezing, as applied to Gulf Coast fish and marine-animal products, and to southwestern fruits and vegetables, that the authors were conducting their research investigations when they observed the highly desirable effects which were obtained by freezing in subcooled sugar and saline solutions. This led to the discovery of "polyphase freezing" or what some prefer to call "flash freezing."

POLYPHASE FREEZING

Controlled supercooling and favorable colloidal action are utilized in The University of Texas polyphase freezing process to flash-freeze foodstuffs. Unusually fast heat transfer is secured by direct contact of food with a chilled medium of high viscosity which is composed of three phases: Solid, liquid, and vapor, hence the term "polyphase." A typical medium is composed of dextrose, sucrose, and water. It is chilled and slowly agitated until a solid phase of finely divided ice particles has formed and is dispersed throughout the liquid. This composition is satisfactorily

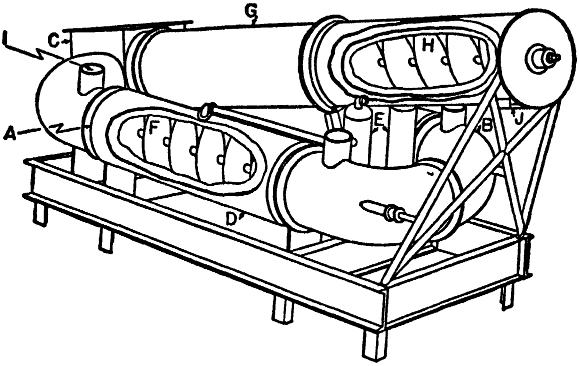

FIG. 17–1. The University of Texas polyphase flash freezer. A, freezer tube; B, return connection to second freezer tube; C, junction box housing separating grid; D, refrigerant jacket; E, refrigerant surge drums; F, freezer helicoid conveyer; G, drainer-tube housing; H, drainer helicoid conveyer; I, feed port for unfrozen food; J, discharge for frozen food.

operated over the range −2° F. to −10° F. and is metastable at these temperatures.

Articles of food are floated in the cold medium and the slow agitation moves the articles with respect to the fluid and also to each other so the individual pieces are prevented from freezing together. Freezing is so fast that washwater or juices adhering to the food surfaces are at once frozen in place and do not dilute the polyphase medium. This film of ice is proof that diffusion of soluble constituents does not occur, solute is not transferred from the freezing medium to the food, nor does the food lose dissolved solids.

The high rate of heat transfer is due to three factors:

(1) The extremely high thermal capacity of the polyphase state.

(2) Increase in the thermal conductivity of the fluid film by the suspended ice particles.

(3) Almost complete elimination of food supercooling by the "seeding" effect.

The polyphase medium removes heat approximately twice as fast as a liquid medium under identical operating conditions. Polyphase media, composed of water and sugars, may be operated in the metastable state at temperatures as low as −10° F., while syrups employed in food freezing are seldom operated below +3° F. Thus it is possible by employing the polyphase media to chill foods in a fraction of the time required by liquid media under ordinary operating conditions.

It has been demonstrated experimentally that the polyphase medium removes a given quantity of heat from cubes of carrot in approximately one half the time required by a liquid medium when the fluid temperatures and other operating conditions are identical. It remains to show the effect of the low operating temperatures which are successfully used by The University of Texas polyphase freezing process.

Let it be assumed that it is desired to remove sufficient heat from carrot cubes so that the temperature of their centers is reduced from an initial value of 77° F. to 4° F. The first portion is to be chilled by contact with a polyphase medium held at −10° F., while the second will be chilled under identical conditions except that the medium will be held at 1.5° F. By means of the Williamson and Adams method, it may be calculated that the ratio of the required time periods is approximately 1:2. Thus it may be stated that a polyphase medium at −10° F. will freeze a given article of food in approximately one fourth of the time required by a liquid medium at 1.5° F.

An important advantage of heat-transfer fluids which can be operated at sub-zero temperatures is that freezing is completed in one operation and no heat is removed in the storage room. By eliminating this period of exceedingly slow cooling, less irreversible damage to the colloidal structure occurs, and a more immediately practical result is that the food does not freeze into a solid mass in the container. Each piece retains its individual character so that it may be removed without disturbing the remainder and repackaging in smaller packages is easily accomplished. Many desirable characteristics of loose-pack frozen foods are emphasized by Flint.

After chilling is completed and the food is removed from the freezer, a film of metastable medium remains upon each article. This film will eventually pass to the stable state in storage but it is better to accelerate the change by dusting the frozen product with a minute amount of dextrose. During stabilization, the coating is changed to a plastic material, consisting of finely divided sugar and a viscous syrup, which adheres tightly to the frozen food and serves as an envelope to retard oxidation and dehydration. Tressler and Evers state that sugars markedly inhibit oxidation and other enzyme action in foods.

MARKETING AND DISTRIBUTION OF FROZEN FOODS

The manufacturing and production of frozen foods has developed to an advanced stage of the art and science, but the marketing and distribution have trailed far behind, as they have in many other types of American enterprise.

The marketing and distribution involve:

(1) Market investigations.
(2) Acceptable packaging.
(3) Variety acceptance studies.
(4) Transfer storage facilities.
(5) Transportation.
(6) Display provision.
(7) Retail market supervision.

The marketing and distribution of quick-frozen products have had a much greater obstacle to overcome than has the development of freezing methods.

Marketing History of Frozen Foods. Between 1925 and 1930 the activity in the new processes of quick freezing caught the imagination of the American public. A new industry was being born under strict Federally established cold-storage regulations. The product was good and quick-frozen products were desired on even the most exacting American tables.

Today most products that have been in the sharp freezer are to the layman, "quick frozen." The wave of enthusiasm for quick freezing is found carrying with it a general acceptance of all frozen products whether they have been barrel packed, can packed, or frozen by one of the accepted quick-frozen processes.

It is obvious that berries frozen in barrels in which it takes approximately two days for the low temperatures to penetrate to the center are not quick frozen. Neither is a 30-lb. can of egg meats that is pulled down to −5° F. in 30 hrs. a quick-frozen product.

But the publicly accepted quick-freezing products have somewhat successfully elevated the admiration of lay buyers to the kindred products that formerly were regarded with much suspicion because they were associated with an historical past that raised some question of doubt in the public mind.

The Market Investigation. The market investigation for any new product is usually too superficial. Market studies that are limited to investigating the demands in a few neighboring rural cities or counties seldom give the true picture. Market investigations, if successful, usually lead to the centers of the nation's consuming population. Large quantities of consumers' products are handled by brokers and special buyers. These men usually know the market demands and are on the lookout for new superior goods.

Beginners in the foods industries seldom appreciate the exacting requirements made by some users. For example, for the strawberry jam industry, a berry that exhibits too many seeds through the glass jar is not desired. Either varieties must be offered that do not have conspicuous seeds, or some treatment must be given the berry preliminary to freezing to cause the berry flesh to plump out sufficiently to partially hide the seed. Yet each of us uninitiated to the jam industry might question whether the trade ever observes the seeds in the buying of a bottle of strawberry jam.

The market investigation should be supported by available samples that are equal to but no better than the standard product that can be delivered in trial lots to the different centers. Any market investigator should recognize that any new competitive product must withstand exacting investigation. The investigation of the product by the brokers will be, most probably, much more analytical than the investigator's inquiries into market channels. A market will come if a superior product at a competitive price in a suitable package is offered the merchants.

Acceptable Packaging. The type of package is or should be studied with handling adaptability, unit cost, shipping charges and sales acceptance kept well in mind.

Glass containers can be used effectively when the product is uniform and attractive and not given to changes with age. When used with frozen foods, ample space should be provided at the top for expansion. Although a decided effort was made in the infancy of the industry to encourage the adoption of the glass package for frozen foods, it faced the disadvantage of being just another glass jar product. Further, glass jars require extensive storage for empty containers.

Cans likewise have met some market resistance except for bulk deliveries. For example, the comparison of the cost of a No. 2½ can of frozen peaches with that of a No. 2½ can of a steam-packed product may be decidedly unfavorable to the frozen stock. When in the same type of package as that used with steam-packed goods the price of the can will be usually the controlling factor in buyers' acceptance. Too often, similar cans mean similar products to the average buyer.

But when special containers of a distinctive nature are used the curious and the discriminating buyers are attracted. They feel they are buying something superior and they may develop this feeling by virtue of the display in a more distinctive package.

For large or wholesome delivery, the large can or the barrel is acceptable as a container. Some confusion may arise by virtue of the fact that there are more sharp-frozen than quick-frozen products available by barrel delivery. Since many buyers do not know the difference, the superior product may suffer by straight price comparison.

Variety Acceptance Studies. In the early researches in quick freezing, some varieties of fruits and vegetables were found to be better than others for freezing and subsequent defrosting. As a result the market learned to accept certain varieties and to resist others.

With newer methods of freezing introduced, some of the products previously considered inferior for quick-frozen processing were found to be superior under the newer procedure. Market inertia is a serious handicap to the introduction of a former disqualified product.

Transfer Storage Facilities. The transfer storage facilities have been a nationwide handicap to the expansion of quick freezing. It is not uncommon to find cities of over one hundred thousand inhabitants not equipped with ample available storage for temperatures below 10° F.

Transportation. The transportation of products frozen to 0° F. has given both rail and truck carriers some concern. In many cases it was solved only when the producers established their own fleet of trucks.

Railroad refrigerator cars have been cooled by the silica-gel absorption system, by dry ice and by mechanical refrigeration. The silica-gel car is still an experimental possibility, dry-ice cars are receiving limited usage because of the cost of solid carbon dioxide, and mechanical refrigeration must usually be supplemented by some dry ice to maintain low temperatures. Salt ice is proving very satisfactory.

The refrigerated truck, cooled either by dry ice or by special brine cartridges for truck construction, is the most favored transportation unit for quick-frozen foods. The terminal speed of delivery and pick up is a distinct advantage to an industry that must carefully watch the low temperatures of its goods in transit.

Retail Market Supervision. If the producer decides to develop the small-package type of quick-freezing retail market, supervision will be very essential. Most producers in states as far removed from the larger industrial districts as Texas, Florida or the west coast have found the wholesale can or barrel package industry far more satisfactory since it relieves the management of the necessary remote control of a host of uniformed retail distributors. If small-package freezing is attempted it should be with the expectation of delivering the shipments in bulk to brokers or jobbers who are organized to give the local areas the needed supervision.

Market Considerations. Quick-frozen products should be marketed for their freshness, quality and uniformity. They should take their place for their all year-round fresh-fruit qualities and not attempt to compete with canned products.

For example, the frozen strawberries going into the ice cream industry are available as a uniform product fifty-two weeks of each year. Many of the leading ice cream manufacturers refuse to use fresh strawberries during the brief season they are available, since, to their custom, a uniform quality, month in and month out, is more essential than the slight saving that would be accomplished by using the fresh berries when available.

In the quick freezing of fruits and vegetables, full ripeness is desirable before the product leaves the vine, tree or plant. This makes possible nationwide distribution of naturally ripened products in contrast to the necessity of ripening in shipment of many fresh items. Often, in taste comparison tests, the quick-frozen product is rated many points superior to the market fresh goods.

Quick freezing has made possible the extended marketing of fruits previously available only in their local areas on account of their delicate structure. For example, Youngberries ship with extreme difficulty and great loss when in the fresh state, but when frozen into hard nuggets they can be dispatched around the world with assurance of safe arrival.

Quick freezing has permitted the selection and shipping of the most useful parts of products. For example, the capping of strawberries reduced the total space and weight essential for shipment. Capped strawberries are subject to immediate spoilage, thus cannot be accepted for fresh shipment. The freezing makes possible the shipment of the useful part only. Similar examples of this advantage of removing the unessential parts may be found in such products as frozen shelled peas, frozen spinach, frozen cherries, etc.

The newer methods of quick freezing will make possible the shipment of berries and fruits without the syrup for preservation. Most buyers and preservers prefer to buy their own sugar.

Probably the factor that has done more to encourage the introduction of frozen fruits in the preserving industry has been their year-round availability. For example, strawberry preserving plants in the producing areas formerly found it necessary to purchase and preserve their year's needs in three to four weeks. This took a heavy investment in plant and berries. Today, a plant of equal annual capacity can operate twelve months per year with only a small fraction of the equipment formerly required, while the investment of raw materials is financed from month to month with probably 10% of the capital originally required.

TABLE 17-1. GROWTH OF COMMERCIAL FROZEN FRUIT AND VEGETABLE INDUSTRY IN THE U. S. IN TEN YEARS *

Year	Approximate Commercial Production of Frozen Pack Products, lbs.
1936	100,000,000
1937	150,000,000
1938	200,000,000
1939	250,000,000
1940	320,000,000
1941	400,000,000
1942	465,000,000
1943	510,000,000
1944	625,000,000
1945	738,053,905
1946	973,281,403

* These values do not include the products that were processed in the several thousand locker plants of the U.S.A.

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SECTION XVIII

LOCKER STORAGE, ECONOMICS AND DESIGN FACTORS

Locker storage consists of a suitable freezer storage plant, preferably held at 0° F., in which cabinets or lockers are provided for rental to the residents of the community for the preservation of their meats and perishable vegetables and fruits. In general, each locker will hold from 200 to 400 lbs. of meat or equivalent produce, and it is made available at from $6.00 to $15.00 per year, this rental charge being dependent upon locker cost factors and facilities offered in addition to the storage space.

The use of locker storage is not of recent origin. There are evidences of the use of some forms of locker storage early in the twentieth century. These uses were not confined to any one area, but ranged from the far-western and the southern parts of the United States to certain sections of Canada. However, these early attempts at locker storage were mostly an effort on the part of some plant operators to offer refrigeration facilities to their friends and patrons who had either game or home-produced meats that required refrigeration facilities.

Until World War I, local butchers did much of the killing, processing and selling of home-produced beef, mutton and pork in their communities. Likewise, the home grocer traded extensively in home-grown fresh vegetables and fruits. Most of the foodstuffs that were shipped into rural areas were dried, canned or cured products.

The remarkable expansion of the locker storage business during the long financial depression from 1929–1936 was greatly augmented by the subsequent food conservation program of World War II. More than five thousand locker plants in North America are now contributing to the preservation of seasonal food products and there still remain on the American continent many possibilities for further expansion of locker storage plants in rural and urban centers.

The increased spread between the price the farmer received at the canneries and packing plants and the higher price he paid to the grocer and butcher for the produce to go on his own table brought about a real grievance. Relief from this price spread was one of the causes for the phenomenal development and acceptance of locker storage service. Growers were again afforded an opportunity to enjoy the benefits of the meats and produce of their own farms at a reasonable cost.

For many of the early locker plants the livestock was slaughtered by the farmer on his own premises and sliced and wrapped by him for storage. Generally, this was not found to be a suitable procedure. The farmer was not an experienced meat cutter and did not realize the need of preparing his meat cuts in proper form and wrapping them in moisture-proof paper. In these early plants no full-time butcher was employed and close supervision of the quality of meat put into the lockers was not possible. Arguments therefore sometimes arose as to who was responsible for the poor quality of meat coming out of the locker.

Most locker plants of today are in charge of one or more full-time meat cutters and butchers who kill, prepare and process all meat that enters the storage locker. The food products available from the modern locker plant are very acceptable when a fresh quality product has been stored in the locker.

With locker plant facilities, the rapid freezing of meat is not very difficult. Since the meat will go directly from the package to the frying pan or cooking kettle, there is very little need to try to preserve its cell structure so that it will have an attractive selling appearance when it has been defrosted. It will be cooked before it is placed before the consumers and the actual crushing of the cell structure by the large ice crystals produced in slow freezing may actually tenderize the meat.

With fruits and vegetables the problem is quite different. Many fruits are to be consumed in the raw form and should have an attractive appearance after defrosting. This requires a very rapid method of freezing at not too low a temperature in order to preserve the fresh appearance desired after defrosting.

Locker plants may be classified as (a) those with refrigeration and service facilities and (b) those offering refrigeration service only. Again they may be classified as (a) those offering cold storage and freezer storage and (b) those offering either freezer or cold storage only.

Plants may be operated independently of other forms of commercial business, or they may be operated in connection with food processing plants, ice plants, creameries, cold storage warehouses, grocery stores, skating rinks, cheese factories or similar community stores and services. If operated as an independent business it will usually require at least 250 lockers to pay the overhead and operating costs of the plant. Locker plants have been successfully operated with as few as twelve locker patrons in connection with country stores, whereas others have served more than three thousand customers in densely populated rural communities.

It must be emphasized that locker plants are essentially for the processing and preservation of food and the *exterior* as well as the interior should be attractive, sanitary, and convenient. The plant should be located very near the center of activity of a community, where it can be patronized with the same ease as the popular food stores. Since probably 75% of the patrons calling will be women, a site convenient to the shopping district that offers parking facilities and electrical, water and sewer connections is desirable.

Locker plants offering only refrigeration service usually consist of one large room held near 0° F. fully equipped with either wood or steel lockers. Such plants are generally an adjunct to a commercial cold storage or ice plant.

This service is sometimes offered as low as $6.00 per yr. for a locker that will hold 200 lbs. of meat or produce. In general, it is not very satisfactory to either operator or patron. It is difficult for the operator to control the quality of meat that goes into this type of storage and, furthermore, it places the full heat load of cooling the meat or other products from a warm condition to the frozen state on the freezer storage room. From the standpoint of the patron it is not desirable since it places on him the responsibility of preparing meat for a form of storage with which he is not familiar, and further, since questionable grades of meat will probably get into storage, the odors within the storage room may be disagreeable and objectionable. Unless stored in sealed packages, storage products often pick up the objectionable odors of a storage room and generally lose weight by evaporation.

In contrast to the locker plant which offers refrigeration service only, there has been developed the ultra-modern locker plant which offers many facilities with service charges and rigid regulations for its patrons. In fact, some of these plants have adopted regulations and fees scaled up so high that the producing farmer, for whom they were originally created, cannot economically patronize them. They have been geared to an urban way of living with the expectation that the farm producer will take at least 50% of the available lockers. For most communities a locker plant equipped with modest services that can be economically justified is recommended. The completeness of the services that can be offered economically will depend upon many factors. Important among these will be the number of patrons, and the needs of the individual family.

The services that might be offered locker plant patrons are:

(1) Slaughtering of livestock.
(2) Chilling of meats.
(3) Salting and pickling of meats.
(4) Smoke curing.
(5) Special storage of smoked and cured meats.
(6) Freezer storage of meat and other food products.
(7) Sharp freezing.
(8) Quick freezing.
(9) Slicing and wrapping of meats.
(10) Poultry cleaning and processing.
(11) Vegetable and fruit processing.
(12) Sausage making.
(13) Lard rendering.
(14) Selling and buying of products.

Several of these services will not be justified in some communities until the patronage reaches a sufficient magnitude to justify the investment in the needed equipment. Several of these items can be added as the demands justify their inclusion.

The investment required will depend upon many local conditions. Investment for plants of 500 lockers have been reported as low as $15.00 per locker for the complete plant and others have been as high as $50.00 per locker. Probably $25.00 to $40.00 per locker is a reasonable and justifiable figure for most areas.

Costs must necessarily be increased if the locker plant owner has been oversold with equipment and unprofitable facilities. Investors should keep in kind that, although the present anticipated business might support a de-luxe plant, competition may later force any plant that is overcapitalized to go into bankruptcy. The installation of a more economical plant in the same or adjacent territory could force an overcapitalized plant into insolvency.

The interior of a locker plant should be thoughtfully designed to provide convenience in the handling of products, attractiveness to those who would store their produce, compactness to give the maximum freezer storage space and insulation economy to afford minimum heat leakage for the insulation used. An economical design for a 300-locker plant might include a cutting, processing and display room, a chill room, a freezer room, the locker storage room, and the necessary space for an office, and the required machinery.

The cutting and processing room should be sufficiently insulated to keep the space cool in summer and warm in winter. Any of the ordinary forms of waterproofed loose or batt insulation might be used in the outside walls and the ceiling. This room should be well lighted and effectively screened. In this room the cutting blocks, grinding machines, saws, wrapping tables and display cases should be housed. The room should be made sufficiently large to permit installation of additional equipment should it be desirable to increase the locker capacity at a future time.

The chill room should be constructed with insulated walls, ceiling and floor for 30° F. storage. It should be at least 12 ft. high to permit use of an overhead meat trolley and, like the processing room, it should be made large enough to permit an increase in the locker capacity of the plant. A good rule to follow is to allow one-half a square foot of floor space per locker for the anticipated ultimate locker capacity of the plant. There is some tendency to overequip this room with meat-handling equipment. The total number of animal carcasses handled per day is not large, so this room should not be equipped as if it were a production packing plant. In the smaller plants the aging as well as the chilling is done in this room. For southern areas, from 5 to 6 in. of corkboard or the equivalent insulation should be used on the walls, ceiling and floor.

The sharp-freezer room should be located so that meat and produce can be moved conveniently from the processing room to the freezer room and thence to the locker room. Since this is the coldest space in the plant it should have a common wall with the chill room and the locker room if possible. This will reduce the insulation cost and the heat leakage. The outside wall and ceiling of the sharp freezer room should have at least 8 in. of corkboard or equivalent, whereas the inner walls between locker, chill room and processing rooms should be at least 6 in. of corkboard or equivalent insulation.

Various types of self-contained shelf freezers are available on the market for equipping this room. Tiers of refrigerated shelves to be used as shelf freezers can be built of refrigeration piping. This room should be designed for −15° F. and the walls, floors, ceiling and doors should be carefully built and well insulated for this low temperature and designed to have at least 10 ft. of head room after the insulation has been applied to the ceiling and floor. A minimum of 60 sq. ft. of floor space for the freezer room of a 300-locker plant and proportionately larger freezer rooms for plants of greater locker capacity is recommended.

Many locker rooms of existing locker plants are not kept cold enough. Southern builders should be especially careful not to construct locker room walls, ceilings and floors according to northern specifications. Not only are the outside temperatures higher in the South and Southwest but many of the southern states experience many more hours of sunshine per week than is common in northern areas.

Locker rooms should be kept at zero degrees or below if complaints from odors are to be avoided. It might be well to refer to the locker room as the "zero room." Maintaining the stored product at this temperature may cost the plant owner more money, but it is a good investment and insurance against food loss and complaints.

Locker room aisles should be at least 30 in. wide. The lockers may be made of either wood or steel. In the early development, when the freezing was done within the locker room, screen or perforated metal walls were used on the lockers to permit a free circulation of air. With the advent of the sharp-freezer room, permitting the freezing to be completed before the produce is placed in the locker, cabinet-type lockers and drawers without perforations have been substituted and quite generally adopted. The dimensions of the locker room can be estimated on the basis of 2.5 to 3 sq. ft. of floor area per locker installed. This will provide for aisles and traffic ways in the room.

Since each locker may contain 250 lbs. of weight, and lockers four, five or six high are generally used, a load concentration on sections of the floor may reach 400 to 500 lbs. per sq. ft. The building floor should be designed to carry this weight at concentrated centers, although the average load per square foot will be only a fraction of the concentrated load, because of the space used for runways and aisles.

Special care should be taken to use odorless asphalts in installing the corkboard or other insulation and great care should be taken in the selection of paints that have no odor after drying. Many cases are on record where storage rooms have been painted with odorous paints or insulation has been set up with compounds having a strong creosote odor; subsequently such walls had to be completely cleaned or reinsulated before storage of edibles could be recommended.

In warm and humid climates provision should be made to prevent warm air from rushing into the locker room as patrons go in and come out. This might be done by constructing an insulated anteroom to the main entrance door, or by providing entrance through a corner of the chill room. This precaution prevents a rapid frosting up of the cooling coils in the locker room.

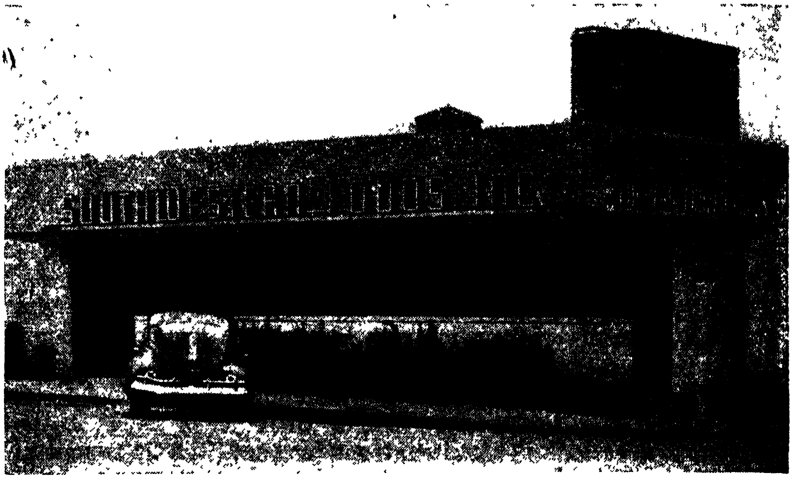

FIG. 18–1. A plant of 2100 lockers at Austin, Texas, equipped with all modern food-processing facilities.

All meats stored in a locker should be sliced ready for cooking, then wrapped in a waxed paper especially prepared for locker storage. The wax with which the paper is treated should remain flexible when cold. The outside of the paper should be untreated so that each package can be readily marked before storage with the date of storage and contents.

Procedure for Using Locker Storage. As previously stated, the customer rents a locker at an annual rate. He then arranges to have the butcher prepare some of his own animals for storage or to purchase at wholesale prices from 150 to 200 lbs. of mutton from the locker plant butcher. Should he want to have some of this meat ground, smoked, or rendered he will pay an additional charge per pound for the portion processed. Once this meat is placed in storage, he is free to call during the open hours of the plant, but must store only fresh, clean, nonodorous foods that are approved by the supervisor. He must check with the supervisor when taking products in and out of the plant.

Service charges that he might expect to pay are:

Butchering	
Calves	$1.00 each
Beeves	$2.00 each
Sheep	$1.00 each

	Cents Per Lb.
Brokerage fee for purchasing meat	1
Chilling, cutting, wrapping and storing meat in locker	1
Making sausage or hamburger	1
Smoking meat	1
Making lard, curing bacon or ham	2–3

Refrigeration Required. The better designed plants require about 2 tons of refrigeration per 100 lockers installed. Some plants in operation use 30% less installed refrigeration capacity than this figure, but too often such plants find it convenient to let their locker room temperature soar up to 10° F. or 14° F. in the midsummer period. This should not be permitted as a general practice.

Time of Keeping Perishable Foods in Lockers. At 0° F. there is no definite limit of time for keeping meats, fruits, and vegetables in locker storage. If preserved in sealed packages, such food should keep for several years but may lose some freshness and color. All foods continue to oxidize in storage unless they are preserved below their lower freezing range or kept in preserving solutions. With some foods this lower freezing range is much below 0° F.; therefore a slow oxidation and loss of color can be expected. In general, meats keep in a very satisfactory condition for six to eight months in zero locker storage.

Estimating the Cost of a Locker Storage Plant. For guidance in estimating the probable cost of a locker plant, some figures of average unit cost of refrigeration requirements and space needs are presented herewith. A typical cost sheet for a 300-locker refrigeration plant is also given.

Estimating Table for Locker Plants.

Locker Room Area: 2½–3 sq. ft. per locker.
Chill Room Area: ½ sq. ft. per locker installed.
Freezer Room Floor Area: 60 sq. ft. plus ⅒ sq. ft. for each locker over 300.
Cost: $25–$40 per locker installed.
Minimum size plant that can produce fair return: 250 lockers.
Concentrated load in locker room: 450–500 lbs. per sq. ft.
Refrigeration required in small plants: 1 ton per 60 lockers in South.
Fair rental charge for lockers: $10–$15 per yr.

Typical Cost Sheet of a 300-Locker Plant.

Land	$ 1,500
Building	3,500
Refrigeration machines	3,000
Lockers	1,200
Insulation	2,000
Equipment	800
Total	$12,000

SUMMARY OF DESIGN CONSIDERATIONS

(1) A locker plant operated as an independent enterprise will require 250 lockers to economically meet the carrying charges.

(2) The storage and freezer rooms should be very compact yet convenient. All insulated rooms should be adjacent to each other. Long, narrow insulated structures are not as economical for refrigeration as are those of square design.

(3) Black-roof temperatures in summer sunlight often reach 165° F. Where single-story buildings are used, roof temperatures should be given special study and consideration.

(4) Saturated atmospheric air at 80° F. contains 15 grains of moisture per cubic foot. Saturated air at locker room temperatures contains less than one grain of moisture per cubic foot. When humid warm air enters a locker room, it quickly frosts the coils and cuts down their effectiveness. Provision should be made for patrons to enter the freezer room through an insulated anteroom or through the chill room to keep the locker room in a satisfactory operating condition.

(5) The purchase of equipment from one reputable manufacturer on the basis of specifications mutually acceptable to the refrigerating engineer and the supplier is desirable. The full responsibility for meeting the specifications can then be readily established.

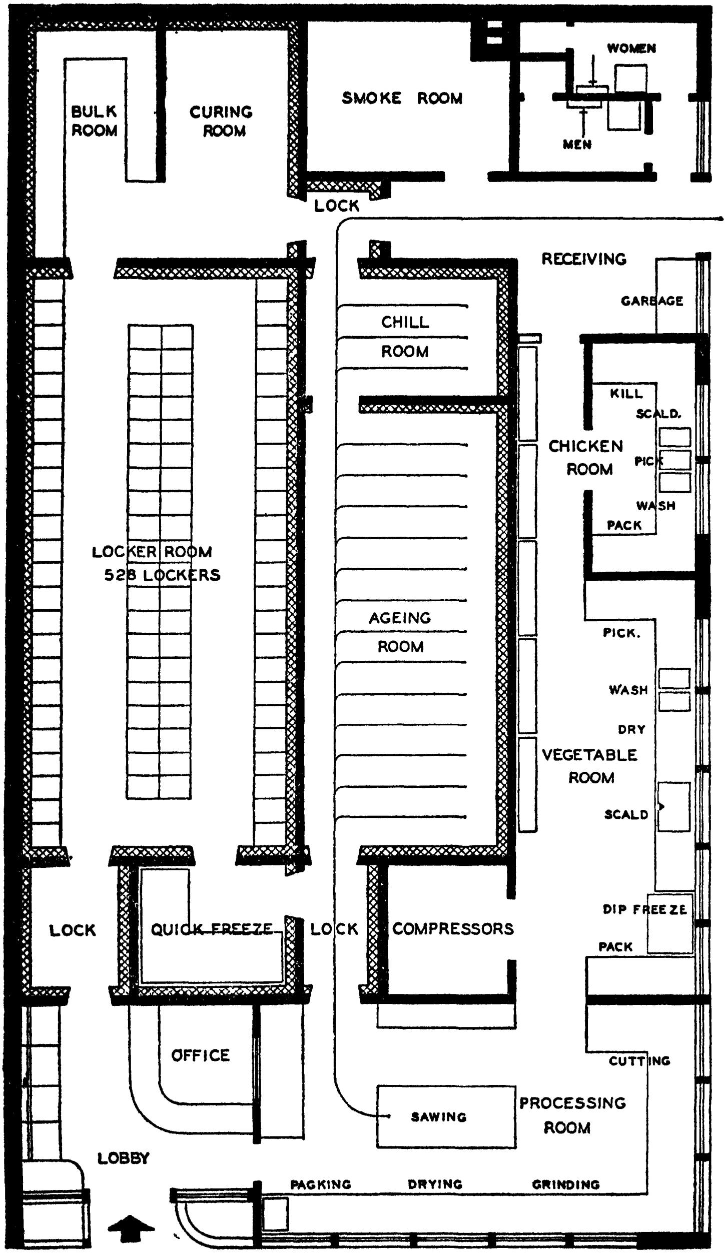

Fig. 18-2. Storage and processing locker plant, 500 locker capacity, 45′ by 80′. (*Competition design by Walter N. Graham, The University of Texas.*)

(6) A locker plant should be designed as a food-processing unit. Cleanliness, attractiveness, durability, convenience, and accessibility are most desirable. Eighty per cent of the daily users will be housewives in the typical community. Expansion of services should be anticipated in the original design.

(7) Reserve compressor capacity is very essential. If two compressors are installed, one can be used to maintain the temperature of the locker and freezer room, the other to operate at the higher back pressures necessary for the chill and curing rooms. In case of emergency, either of these machines should have sufficient capacity to carry the entire load and should be interconnected to meet these conditions.

(8) If the available electric power is not dependable, auxiliary Diesel or gasoline engine drives should be provided.

Why Locker Plants Have Been So Successful in Farm Communities.

(1) They have made possible the processing and preservation of farm meats at any time of the year. This has made farm-grown meats available at cost to the farmer producer.

(2) They have reduced the feeding cost of animals fattened for home consumption. With a locker available, any season is killing season and the fowl, hog, calf or lamb can be slaughtered when fattened, without waiting for cold weather.

(3) Locker processing of fruits, meats and vegetables requires less time for preserving than hot processing.

(4) By locker storage farm homes have found it possible to save most of their perishable vegetables and fruits of the season of plenty for the season of scarcity.

(5) With a locker plant in the neighborhood community, processing of surplus foods for commercial marketing has been made possible by freezer storage refrigeration.

Home Lockers Complementary to Locker Plants. The introduction of the home freezer locker is not competitive but is complementary to the plant locker. The home locker should be kept full of a wide variety of frozen foods, some cooked, some fresh, but should represent a wide selection of items especially processed for quick serving. The food stored at the locker plant should represent the entire season's supply of frozen surplus fruits, vegetables and meats. The home locker should be stocked from the locker plant, and much of the food brought from the plant should receive

further processing to make it ready for emergency needs of the home.

TABLE 18-1. AVERAGE WEIGHTS OF CARCASSES

Kind of Animal	Weight in Pounds
Beef..	450
Baby Beef...........	250
Calves...	100
Sheep..............	75
Hogs. .. .	200

SECTION XIX

STORAGE HOUSE CONSTRUCTION

Refrigeration Required for Storage and Freezer Plants. The size of a cold-storage warehouse is specified by the cubic-feet content requirements of the rooms, including the space occupied by the pillars and columns. In rating the capacity of a cold-storage plant the space given over to facilities such as compressors and elevators and to the trucking halls and shipping space is not included. In general, the income space of the cold-storage plant is that included in the cubic feet of rated size.

Most of the successful cold-storage plants within the United States are the center of other commercial activities of the same or affiliated corporation. Only the very large cold-storage plants are likely to be financially successful when operated as cold-storage warehouses only. There are certain overhead costs that must be met by any cold-storage plant whether it is of 100,000 cu. ft. capacity or 500,000 cu. ft. capacity. This requires the small storage house which has higher relative unit costs to operate at a great disadvantage against larger houses even if there is plenty of business to keep both houses reasonably filled. Since there is nothing the small storage house can offer that is better than the large house can supply, the charges per cubic foot of storage space must be the same to meet the competition.

The allowable charges for storage space will vary with many factors, such as amount of space needed, length of time product is to be held in storage, temperature which the product must maintain, and the nature of the product. In the average cold-storage house, the income for the total space rented per year will be from 8 to 15 cents for the cooler space above 30° F. and from 14 to 24 cents per cu. ft. for the freezer space below 32° F. In a typical cold-storage plant the gross income for all storage will vary from 10 to 20 cents per cu. ft.

A cold-storage house that nets 8% on the total investment considers that it has had a good year. When the income falls below this, the manager generally begins to investigate the possibilities of taking on additional commercial enterprises that can be associated with the cold-storage industry to make the cold-storage house pay.

Cold-storage Houses. Cold-storage houses to be effective must be properly constructed and properly located. To be a financial success they should be built where railroad facilities are ample, and at a point from which wholesale distribution is readily promoted. Often this may be at a point on the main railroad en route from the point of production to that of consumption, but the more natural point of storage is near either the point of production or consumption, since this saves a double freight handling charge on the goods. Where water transportation is available, dockage provisions should be considered in relation to the house.

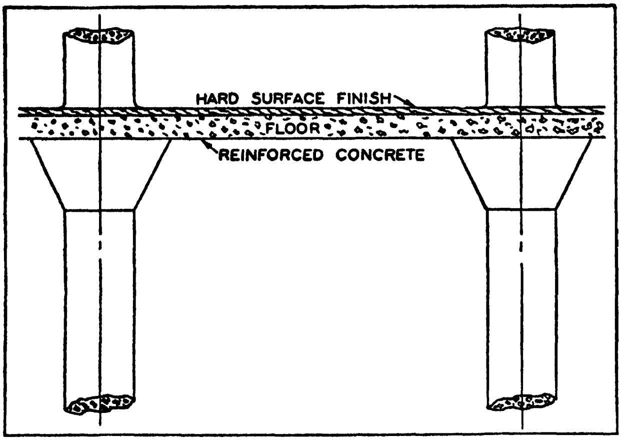

Fig. 19–1. Reinforced concrete construction suitable for cold storage.

A walk through some of our American storage houses reveals many things to be avoided in storage-house construction; low beams, inconvenient air ducts and dripping ceilings all indicate that the net income possibilities have been considerably reduced by lack of forethought in design.

Fireproof construction is recommended for all cold-storage work. Where this is not feasible, mill type wood construction is very satisfactory. Reinforced concrete construction is preferable to steel construction in the design of fireproof cold storage, since any small blaze within a vault or room would be sufficient to warp the steel columns and beams and make further use of the space undesirable. In making a building fireproof, it can readily be made also vermin and rodent proof, since most fireproof materials offer to bugs or rodents little that can be devoured or penetrated.

Cantilever slab construction, shown in Figure 19–1, is well adapted to storage-house construction. This type of design permits running refrigeration piping in any direction, since there are no beam or girder obstructions. Likewise fan ducts or similar framework can be installed without obstruction, and the absence of the beams and girders improves the light distribution and permits the loading of trucks to nearly the full height of the room.

Refrigeration Required for Cold Storage. For estimating purposes, to determine the amount of refrigeration needed for cold and freezer storage, a series of graphs is given herewith. These values are satisfactory for average conditions in the southern latitudes of the United States and are 10 to 20% high for northern areas. For actual needs the requirements should be carefully computed.

The factors that must be considered in cooling a storage room are: (1) number of changes of air in room in 24 hrs., (2) insulation of the room, (3) size of room or vault, (4) difference of temperature between inside and outside of storage space and (5) quantity and character of the material in storage.

Effect of Changes of Air upon Refrigeration Requirements. Changes of air are brought about in many storage buildings by leakage through doors, elevators and windows, and by infiltration through the walls. In other houses fresh air is introduced to reduce the percentage of CO_2, the undesirable odors, and the foul gases.

To show the air change effect on the refrigeration requirements of a cooling room 50 by 20 by 10, or 10,000 cu. ft. capacity, the refrigeration required will be computed for one air change per 4-hr. period with outside temperatures averaging 80° F., and the room at 35° F.

Computations. One ton of refrigeration equals 228,000 Btu per 24-hr. period or 200 Btu per min. The weight of a cubic foot of air at 35° F. is 0.08 lb.

The specific heat of air at this temperature is 0.24.

The heat that will have to be extracted every 24 hrs. will be: $0.08 \times 50 \times 20 \times 10 \times 0.24 \times (80 - 35) \times \frac{24}{4} = 51{,}840$ Btu.

This is equal to 0.22 ton of refrigeration just to cool to 35° F. the six changes of air in 24 hrs.

Effect of Insulation. The function of the insulation is to cut down the heat transfer by conduction through the several sides of the room. In cold storage it is only necessary to consider those sides of the rooms where there is a difference of temperature within and without the room walls. In the above problem it will be assumed that the floor, ceiling, one side and one end are surrounded by rooms of similar temperature.

This would leave heat transfer through the walls on one end and one side between the outside atmosphere at 80° F. and the room temperature at 35° F. We will assume the storage house has a 14-in. brick wall with a 3-in. corkboard lining. From insulation tables this will conduct 0.07 Btu per square foot of wall surface per hour per degree of temperature difference.

Computations. Wall area × factor of conductivity × difference in temperature of inside and outside = Btu entering by conductivity through outside walls.

$$[(50 + 20) \times 10] \times 0.07(80 - 35) = 2205 \text{ Btu.}$$

If the lining had been omitted, the coefficient 0.07 would have been replaced by 0.28 and the results would have been increased 4 times.

$$[(50 + 20) \times 10] \times 0.28(80 - 35) = 8820 \text{ Btu.}$$

In this example, then, the room lining or insulation cuts down the heat infiltration from 8820 Btu to 2205 Btu.

Effect of Storage Room Size. The computations affected by room size are evident. Small rooms and small storage houses require a much greater amount of refrigeration per cubic unit than larger rooms and houses. This is caused by:

(1) Greater percentage of total change by door and window openings.

(2) Greater average percentage of wall surface surrounded by high temperatures.

Effects of Outside Temperature. Since heat flow is proportional to the temperature difference inside and outside the room, the other factors remaining constant, temperature requirements and conditions greatly affect refrigeration demands.

Freezer storage in Birmingham with an average yearly atmospheric temperature of 63° F. is a much more different problem from freezer storage in Milwaukee with an average yearly temperature of 45°. Freezer storage at 15° F. produces a far less refrigeration demand than freezer storage at 0° F. Equally, cold storage is affected by similar factors, and the smaller the storage the more greatly is this effect felt.

With the average cold-storage plant, the operating force soon learns the requirements and characteristics of each storage room. The first four factors just discussed become fairly well stabilized from week to week, and no great storage demand changes are made from these sources.

Effect of Class of Incoming Products on Refrigeration Demand. The nature and quantity of incoming and outgoing perishables present a questionable problem to the operating force of a cold-storage plant. This is true of the freezer rooms, especially if the storage periods are short. In computing the heat removal necessary in the refrigeration process, several examples will be given.

Case 1. Cooling Materials to Temperature Above Freezing. When materials are placed in cold storage to be cooled to a temperature above that of freezing, the values that must be known to compute the amount of heat to be removed are: (1) Weight of material. (2) Required change in temperature. (3) The specific heats of the material above freezing.

For example, if 10,000 lbs. of onions are received at 75° F. to be cooled to 32° F., the following computations would give the heat removal required from the onions:

The specific heat of onions above freezing is 0.9.

The temperature drop is 75 − 32, or 43° F.

The heat to be removed will be then $10{,}000 \times 0.9 \times 43$, or 387,000 heat units.

This corresponds to $\frac{387{,}000}{144}$, or 2687.5 lbs. of refrigeration, or $\frac{387{,}000}{288{,}000} = 1.34$ tons of refrigeration.

Case 2. Cooling Materials to Temperatures Below Freezing. When materials are to be cooled to a temperature below freezing, the values that must be known to compute the amount of heat to be removed are: (1) Weight of material. (2) Required change in temperature above 32° F. (3) Specified heat above freezing of material. (4) Latent heat of material. (5) Specific heat of material below freezing. (6) Temperature below freezing to which material is to be cooled.

For example, if 20,000 lbs. of fish are received at 72° F. and are to be frozen and stored at 24° F., the following computations would be necessary:

The specific heat of fish above freezing is 0.82.

The temperature change above freezing is 72 – 32, or 40° F.

The heat to be removed above 32° F. is then, 20,000 × 0.82 × 40, or 656,000 Btu.

But at freezing, fish have a latent heat of fusion of 110 Btu per lb. To freeze, then, will require 110 × 20,000 or 2,200,000 Btu.

Below freezing, these same fish have a specific heat of 0.43.

The temperature change below freezing is 32 – 24, or 8° F.

The heat to be removed below 32° F. will then be 20,000 × 0.43 × 8, or 68,800 Btu.

The total heat removed in cooling the 20,000 lbs. of fish is as follows:

Heat removed from 72° F. to 32° F.	656,000 Btu
Latent heat removed at 32° F.	2,200,000 Btu
Heat removed 32° F. to 20° F.	68,800 Btu
Total heat removed	2,924,800 Btu

This corresponds to $\frac{2,924,800}{144}$ lbs. of ice melting, and if this were done in 24 hrs. it would require 2,924,800/288,000 or 10.15 tons of refrigeration.

TABLE 19–1. ESTIMATED TONS OF REFRIGERATION FOR COLD AND FREEZER STORAGE (SMALL PLANTS)

Cubic Feet of Space Refrigerated	Tons of Refrigeration Required for 10° F. Rooms	Tons of Refrigeration Required for 34° F. Rooms
1,000	1½	¾
2,000	2¼	1¼
5,000	4	2½
7,500	5	3¼
10,000	6	4

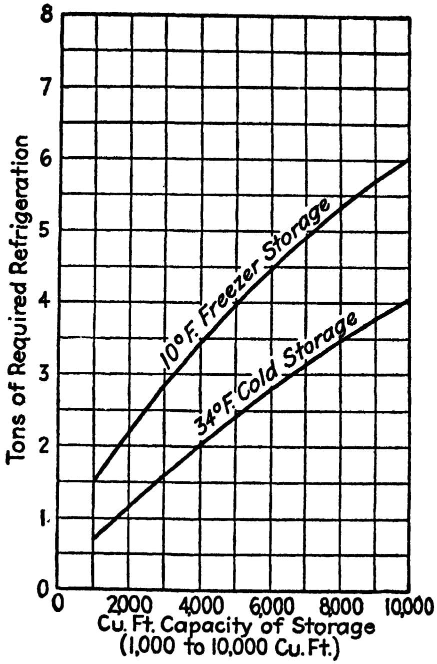

FIG. 19-2. Refrigeration demand—small storage houses.

TABLE 19-2. HEAT GIVEN OFF BY ELECTRIC LIGHTS AND PERSONS

Lamps, Size in Watts	Btu per Hour Given Off
15	51
25	85
40	136.5
60	204.6
100	341.0
200	682.0
Human adult at work	520

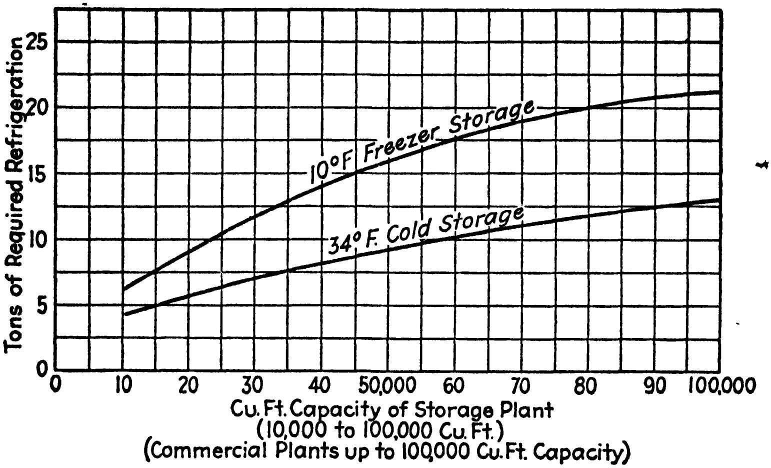

Fig. 19–3. Refrigeration demand—medium size cold storage houses.

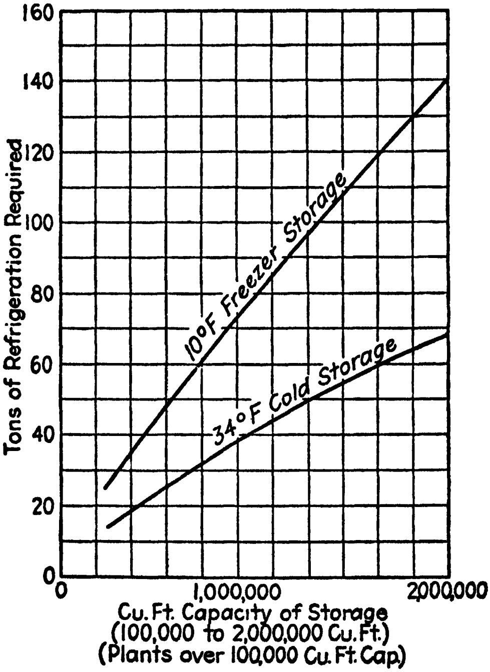

Fig. 19–4. Refrigeration demand—large cold storage houses.

TABLE 19-3. ESTIMATED TONS OF REFRIGERATION FOR COLD AND FREEZER STORAGE (LARGE PLANTS) *

Cubic Feet of Space Refrigerated	Tons of Refrigeration Required for 10° F. Rooms	Tons of Refrigeration Required for 34° F. Rooms
10,000	6	4
20,000	9	6
40,000	14	8
60,000	17½	10
80,000	20	12
100,000	22	13
500,000	50	25
1,000,000	75	37
2,000,000	140	67

* These values are for the average conditions in the latitude of 30° N., or in Jacksonville, Mobile, New Orleans and Houston. For 40° N. latitude these values can be taken at 15% less.

SECTION XX

REFRIGERATION OF MEAT, FISH AND POULTRY

The refrigerated storage of meat may be divided into two classes —cooler storage and freezer storage.

Cooler storage is confined to storage above the freezing point. For fresh beef, mutton, pork or poultry, the practice does not vary greatly. Only a very limited amount of fish is handled in cooler storage. Cooler storage is used also in the curing processes of pork when pickling, salting or smoking are employed.

There is no uniformity of opinion on the best practices in cooler storage; there are so great a number of variables to control that no one practice is acceptable to all packers.

Meat Cooler Storage. Meats in cooler storage must be protected against:

(1) Shrinkage.
(2) Discoloration.
(3) Mold growths.
(4) Bacterial spoilage.

The work of Loeser, Schmid and Ewell is of interest. The researches of the U. S. Department of Agriculture have contributed much to our knowledge of the storage problem.

Shrinkage. Factors affecting shrinkage are:

(1) Humidity of the room.
(2) Temperature of the carcass.
(3) Movement of air currents.
(4) Ratio of exposed surface to weight.

Low humidities cause excessive shrinkage of all types of meat, but these lower humidities generally retard the bacterial spoilage action. Ewell states that the "equilibrium vapor pressure over beef has been found to be approximately 99.2%. Since the humidity in the room is far below this value, the actual humidity at the surface will be somewhere between the two."

Loeser reports that the bacterial growth on beef stopped at 92% and grew with great rapidity at the highest humidity attainable, 99%. Likewise mold growth was at a maximum at 99% humidity. Schmid and Loeser found that the ratio of the exposed surface to the weight of a typical quarter of beef was 0.175 sq. ft. of surface per pound of weight.

For most classes of cooler storage of meats humidities from 85% to 90% seem most desirable. The lowering of the humidity has a much greater effect relatively in producing shrinkage than the increasing of the temperatures. An increase of temperature from 32° F. to 40° F. increased the shrinkage only about 25%, while a change of humidity at 32° F. from 95% to 85% increased the shrinkage 300%.

A quarter of beef of 200 lbs., held at 85% humidity and 32° F., will shrink probably at the rate of two-thirds of a pound per day in still air. The motion of the air from a unit cooler will increase this loss. A movement of 10 ft. per min. will double the loss. With higher velocities the increase of loss will be relatively less per unit increase of velocity.

The bacterial growth per unit increase of velocity is usually less when fat is present, on account of the lower percentage of water present.

Loss of Bloom or Discoloration. The researches of various experimenters confirm the belief of the industry that discoloration or loss of bloom is directly traceable to oxidation of the red cells or hemoglobin in the meat.

Continued oxidation results in a dark purplish red flesh and finally in a bluish green. Since much of the trade judges the tenderness and freshness of the meat by its color, this loss of bloom is a serious handicap.

In storage the higher humidities decrease the discoloration, whereas increasing air velocities increases the discoloration rate.

Mold Growth. In certain areas of the world mold was considered a "curing" agency to make the meat better. Many old-time family doctors prescribed this form of cured meat for their patients. *When the mold growth starts on meat so does its decay.* Even the thin green mold is a sign of incipient deterioration. In general, the depth of mold beneath the meat surface is equal to the height of the mold (more commonly called whiskers) above the meat surface.

Investigations in Europe with carbon dioxide concentrations up to 20% indicated that the mold growth can be inhibited sufficiently to increase the storage time 150%. Ten per cent CO_2 concentration doubled the storage time.

Ozone likewise has been used as an inhibitor of mold growth. Up to the present time, Europe has been more enthusiastic about ozone than America. Questions of increased oxidation and the rapid decomposition of the unstable ozone have not been as satisfactorily answered to the American packer as he would like.

Bacterial Growth. As has been indicated, bacterial growth can be retarded by lowering the humidity. Likewise, increasing the air velocity generally decreases the rate of bacterial growth.

Bacterial growth is greatly retarded by the presence of carbon dioxide. Much of the meat imported to England is carried in sealed containers carrying 20% carbon dioxide.

The necessity of meeting all of these different conditions in meat storage requires experience and judgment. Since some of the same factors that cause one form of deterioration act also as inhibitors for other forms, considerable care must be taken in acquiring the balance that is most economical.

Freezer Storage. Storage at 27° F. to 28° F. of meats is practised in many places. Although this cannot be classified as sharp freezer storage, it is somewhat below the beginning freezing point of most meats.

Freezing to these temperatures is a reversible process and is a recommended procedure for meat that is to be held somewhat longer than the general line of products handled.

Sharp-Freezer Storage. Long-term storage of meat can be most readily accomplished by holding it at or somewhat below 10° F. Below 10° F., bacterial and mold growth is inhibited practically 100%, fats show no tendency toward oxidation to rancidity, and the bloom and weight are preserved.

It is common practice to wrap meat frozen to these temperatures in moisture-proof or heavy wrapping paper to reduce the moisture loss and to facilitate the removal of the meat from the storage bins. Unwrapped meats stored together become very firmly frozen together. A paper wrapping around each piece facilitates removal by preventing the different pieces from freezing together.

Meat frozen at temperatures between zero and 10° F. are improved in their tenderness and palatability.

The Richardson and Scherubels Reports on sharp-frozen meat at 10° F. indicate that meat frozen for 600 days was free from bacteria at a depth of 0.2 in. below the surface. Meat frozen at 27° F. showed a bacterial penetration of 0.2 in. in 30 days.

The freezing range of beef is from 30° F. to −60° F. Not all oxidation will be stopped until freezing below the lower part of the range is complete. However, freezing to 10° F. or slightly below is sufficient to preserve most meats for several months. There is no noticeable discoloration in three months' time at these temperatures.

Upon defrosting, such meats are less stable than those held above 27° F. Many users prefer to have meats that are to be stored at these lower temperatures cut up into their retail portions, then wrapped and frozen. When this procedure is followed, the frozen portion can go directly from the refrigerator to the cooking vessel without any intermediate cutting.

COLD STORAGE IN MEAT DISTRIBUTION

The meat-packing industry is outstanding as a business enterprise in that it offers to the producers of cattle, hogs and sheep an immediate cash market for their animals. This is made possible by refrigeration. The thousands of head of livestock that come to the markets each day without any supply control except the desire of the seller to turn his cattle, hogs or sheep into cash are seldom held over without a sale for more than 24 hrs.

To make the handling of large quantities of meat possible, each packing plant is equipped with cold-storage rooms for both chilling and holding the carcasses. In addition to this, many packers also have their own fleet of refrigerator cars and supplemental branch refrigeration houses distributed over their trade territory. This makes possible the shipping and holding of carloads of meat at the major distribution centers.

Such a system makes it possible for meat packers to accept considerable variations in their livestock purchases. The meat passes through the chilling room in two days and may remain in the holding rooms for three weeks at or near freezing temperature. Should there be a glut of the market, sharp freezing of part of their purchased meat may follow. The frozen meat can be kept for many months without injury to the edible quality.

All meat going into interstate commerce and all export meat falls under the scrutiny of Federal inspectors. This includes (1) process sanitation, (2) ante mortem examination, (3) carcass inspection, (4) finished product examination, (5) laboratory tests of questionable meat and (6) policing and control of condemned products. About two-thirds of all beef, pork and mutton killed for consumption within the United States is subjected to Federal inspection. The refrigeration engineer must keep fully informed on the meat inspection laws.

In shipping meats, precautions should be taken to assure availability of amply cooled refrigerator cars and trucks before loading. Railroad refrigerator cars will require 24 hrs. of preicing before loading with chilled meat, and long-haul trucks should be thoroughly precooled before taking on the perishable load. For sanitary control, these cars should be washed with soap and very hot water after each shipment.

Where Federal inspection is not required, local, state or municipal laws may impose a similar inspection to protect the consumers against unsanitary meat.

COLD STORAGE OF FISH

Most fish going to the market have been sharp- or quick-frozen. For local markets many fish are packed and transported to the cold-storage house at temperatures near the freezing point. Great care must be taken in the preservation of such fish.

If fish are frozen, the enzyme, the bacterial and the oxidation action are all decreased to nearly zero, but when not frozen all three of these decomposing procedures will seriously affect the quality of the product. For local refrigeration purposes, an ice covering with some salt may suffice, but if the fish are to be kept in the storage house for many days, they should be placed in a room between 22° F. and 28° F. and held.

Fresh fish have but little odor. Stale fish are readily detectable by their strong odor of putrefaction. No amount of supplementary refrigeration treatment can restore stale fish to the condition of an edible product.

Shellfish and shrimp are often furnished the local markets in an unfrozen condition. These likewise should be accepted in the cold-storage plant if they have a fresh odor. Like other sea and fresh-water foods, shellfish and shrimp have been protected by a water or saltwater bath during their natural life. They deteriorate very quickly when exposed to warm air. If they are delivered to the storage house for holding for a short time, they should be held near the freezing point until delivered.

The freezing of fish to hold them for the market has been a commercial enterprise for the past eighty years, and today it has reached the proportions of approximately a quarter billion dollars annually in the North American continent alone. The greatest problem in the handling of frozen fish and shellfish is that of freezing them while they still have freshness approaching that of live fish. A problem very closely related to the freshness of fish is the bacteriological and sanitary condition at the time of freezing. Only fresh, sanitary foods should be frozen.

Special care should be taken to clean and prepare any food that will probably be eaten in the raw state after it is removed from the storage rooms. Serious epidemics have originated from distributing inadequately washed and treated frozen or refrigerated sea foods that have been taken out of polluted waters, then served on tables with too much confidence in their wholesomeness. Since freezing does not effectively reduce the bacterial count of the foods frozen, great care should be taken to permit only thoroughly sterilized shellfish to be stored where there is the possibility of consumption as raw food.

In the shellfish class, shrimp, scallops, lobsters, squid and crab meat are the principal foods to be frozen. Of this group, shrimp take the lead, equaling more than the total of all other shellfish frozen.

Shrimp of the American continent are found primarily in the Gulf of Mexico and the Pacific Coast. They are caught by a system of trawling and are then taken either to the shore or to tender boats in ice packing. In the cleaning rooms they are usually beheaded before freezing. A very small percentage are beheaded, deveined and precooked before freezing. The amount of ice used in packing for the trip to the cleaning rooms is often inadequate and the fish arrive for cleaning and freezing in a doubtful state of preservation.

Although considerable frozen shrimp arrive in the storage rooms in an advanced state of deterioration, there are no very satisfactory methods of detection available to the storage house manager except to defrost a sample and either smell or taste the product. Several methods of testing have been proposed to determine when shrimp have reached the critical condition but to date none of these are as reliable as the smell-and-taste procedure.

POULTRY REFRIGERATION

Because of the wide divergence of opinions expressed in printed circulars coming from both Government and private sources, much confusion prevails in the procedures of handling poultry. In some sections of the United States ungutted fowls prevail on the market.

whereas in other areas poultry that has been killed and placed on the market undrawn is considered inedible.

Tastes have been influenced considerably by the procedures that have been existent in the dressing of the poultry consumed. Individuals who have been accustomed to eating storage poultry that has not been drawn until just prior to cooking often express a preference for the taste of such prepared fowl. Those who have been accustomed to completely eviscerated birds are very critical of the taste of uneviscerated poultry.

Although some claim it is possible to prepare and control undrawn poultry in the laboratory so that it will equal eviscerated birds, *the safest and best practice in poultry preparation is to eviscerate or draw all birds.*

When entrails containing partially digested foods and digesting acids are allowed to remain within the carcass, there will be migrations of these off tastes and bitter acids to the flesh of the poultry. Such osmotic and vapor pressure action cannot be entirely stopped by the freezing of the undrawn carcass even when the temperature is very carefully controlled. The osmotic and vapor pressure effects will increase with temperature variations.

The Dressing and Packing of Poultry. The poultry-packing plant should be a clean establishment. Much progress needs to be made in poultry-plant sanitation and handling. Poultry may be dry picked, slow-scald picked and scald picked.

Dry picking is done for special trade and requires close supervision. The carcass must be picked while still very warm, as the feathers will tighten up as the flesh cools. Dry-picked poultry presents a very satisfactory product for the market. The reclaiming of the feathers is more readily carried out when they can be removed dry, then cleaned and sterilized for the trade.

Semi-Scald Picking. The birds are killed and plunged into a hot bath at 125° F. to 130° F. for a period of 30 to 60 sec. This loosens the long feathers for removal by pulling. The pin feathers that remain can be removed by careful hand picking, or this same job can be more effectively done by drying the carcass in a blast drier, then dipping it in a paraffin-based special wax. When the wax has cooled, the wax and the pin feathers are pulled off in one operation.

Scald picking is accomplished by dipping the bird for 2 to 5 sec. in water at 170° F. to 200° F. The entire carcass except the head is submerged. The long feathers are pushed off in a surface motion, then the pin feathers are removed either by hand picking or by the wax-bath process.

Poultry-Picking Machines. Recent developments in poultry-picking machines bring promise that the hand picking methods will rapidly disappear, as machine picking is both cheaper and more satisfactory.

Some pin feathers must necessarily be removed by hand from under the wings and between the legs and the body, but this is not difficult. Some criticism has been made that the surface of machine-picked poultry is not as attractive as that of the hand-picked bird, because of the action of the rubber fingers of the machine on the skin and flesh. This difficulty is being rapidly overcome by some changes in the design of the machine.

When the poultry has been cleaned by one of the processes described, evisceration should follow and an examination of the condition of the entrails should be made to insure a safe, healthy product. The finished bird is then passed to the inspectors to be examined and graded for the market.

Freezing of Poultry. Poultry improves with sharp and quick freezing. Many individuals keep their chicken, guinea, duck, goose and turkey carcasses for several weeks in sharp-freezer storage to improve their quality.

For commercial freezing the procedure is to:

(1) Immediately after cleaning and drawing the bird, chill at 32° F. This will require 5 to 8 hrs.

(2) Wrap and quick freeze as soon as possible, then hold the carcass at the quick-freezing temperature.

(3) The best results do not permit the holding-room temperature to vary appreciably. Changes in flavor, weight and color can be prevented by maintaining the storage temperature and humidity constant.

Holding the temperature of frozen poultry at −10° F. to −20° F. is recommended and a humidity of 90% is desirable. Low humidities result in dehydration of the flesh and consequent loss of weight.

Poultry wrapped in moisture-proof bags and held at a temperature of −20° F. can be kept for one year without appreciable change. Care should be taken to not permit too much air to be circulated in the storage room.

Defrosting. Defrosting, if necessary, should be as carefully done as quick freezing. The process of defrosting is slower than that of quick freezing. If thawed out in a warm room, the outer portion of the carcass will not be acceptable by the time the inner portion of the body has thawed out. Thawing of the poultry in the chill room is slower than in a warm room, but the flesh will be in better condition.

Whenever possible, the holding of the temperature of frozen poultry below freezing temperatures until it is transferred to the roasters or broilers is desirable.

U. S. Standards and Grades for Dressed Poultry. For merchandising, several grades have been set up for dressed poultry. However, these grades have more to do with the appearance and apparent condition of the dressed bird than with its palatability. It is questionable whether a poultry inspector could distinguish between a U. S. Grade AA and a U. S. Grade B turkey by its taste and edibility when prepared by the same cook. However, the grades would normally differ widely in price to the buyers of such poultry stock as they come from the broker.

CLASSIFICATIONS OF POULTRY

Young chickens dressed for the market are classified largely by age, independent of sex.

A *broiler* is under twelve weeks and usually weighs less than 2½ lbs.

A *fryer* is between thirteen and twenty weeks old and usually weighs under 3½ lbs.

A *roasting* chicken is five to nine months old and still tender enough to be cooked by roasting.

A *capon* is a castrated male chick that has been fed especially for table use. They may be 5 to 10 lbs. at eight to ten months.

Stags are young male chickens too old to be classified as roasters and too young to be classed as roosters.

Hens are usually over one year and go to the market either for canning or for stewing.

Roosters are old male birds, usually sold for stewing.

Fowl by definition might be any male or female mature bird. As used by most brokers and hotels, it applies to mature female chickens or ducks or guineas.

Turkeys are young when less than one year. The market divides them as hens and toms. In some areas hens are preferred, whereas in other sections toms are favored. From the standpoint of edibility, the feeding prior to marketing is more important than the sex.

TABLE 20–1. SPECIFICATIONS FOR EVISCERATED BROILERS, FRYERS, ROASTERS, STAGS, CAPONS, FOWL, AND COCKS
(Minimum Requirements)

Item	U. S. Grade A	U. S. Grade B	U. S. Grade C
Meat quality (except of fowl and cocks)	Soft meated	Fairly soft meated	Slightly coarse meated
Fleshing	Well fleshed	Fairly well fleshed	Poorly fleshed
Bleeding	Well bled	Fairly well bled	Poorly bled
Dressing:	Well dressed	Fairly well dressed	Poorly dressed
Protruding pinfeathers	None	None	None
Nonprotruding pinfeathers	Practically free especially on breast	Few, scattered, on any part of carcass	Numerous, over any part of carcass
Bruises	None, except slight reddening of skin May be accompanied by slight reddening of flesh. Breast practically free and few such defects on remainder of carcass	None, except slight reddening of skin. May be accompanied by slight reddening of flesh. Breast practically free from such defects	None, except slight reddening of skin. May be accompanied by slight reddening of flesh
Abrasions and discolorations	Few slight permitted	Permitted	Permitted
Tears of skin	Up to 2 in. on back and wings permitted	Permitted on back and wings and one tear up to 3 in permitted on breast or legs	Permitted
Sewn skin	None	None	None
Broken and disjointed bones (See definition of Grades A, B, and C, Dressing and General Requirements)	One nonprotruding broken wing bone or one disjointed wing permitted in broilers and fryers if no appreciable bruise or blood clot. Broken protruding wing bones may be clipped off and wing tips may be removed if desired. No complete member, such as wing or leg, may be missing	One nonprotruding broken wing bone or leg bone or 2 disjointed bones permitted if no bad bruise or blood clot. Broken protruding wing bones may be clipped off and wing tips may be removed if desired. No complete member, such as wing or leg, may be missing	Disjointed bones or broken nonprotruding bones in fleshy parts permitted if no bad bruise or blood clot. Broken protruding wing bones may be clipped off and wing tips removed if desired. May have one complete wing missing or, if of Grade B quality, may have one leg or one wing missing
Deformities	Slightly curved breast bone permitted	Dented or notched breast bone. Slightly crooked breast bone Slightly crooked back, wings, or legs permitted	Hunchbacks, crooked breast bones, and other deformities permitted
Freezer burn	Small pock marks on neck or wings	Small pock marks on any part of carcass. No large dried areas	Serious pock marks of large dried areas on any part of carcass
Picking	Dry-picked or semiscalded	Dry-picked, semiscalded or hard-scalded	Dry-picked, semiscalded or hard-scalded
Packing	Dry or ice	Dry or ice	Dry or ice

All birds must be singed and the following parts removed in evisceration: Head, shanks (at hock joint), crop, windpipe, esophagus, entrails, gall bladder, lungs, kidneys and oil gland.

Geese likewise are classed as young when under one year. Young geese are not classed as male or female. Some areas put old ganders in a different class than old geese.

Ducks are classed as ducklings and ducks. The duckling usually does not exceed four months. Birds of either sex older than this are sold as ducks.

Squabs and *pigeons* are marketed with less accurate records of age. Since a five weeks' squab weighs about ¾ lb., and it is at this age that they take actively to wing, young pigeons that weigh just under ¾ lb. are classified as squabs. When they become more active in flight and harder of muscle they are sold as pigeons.

TABLE 20–2. SPECIFICATIONS FOR U. S. GRADES FOR EVISCERATED, FEDERALLY INSPECTED TURKEYS

(These standards for individual birds represent minimum requirements for each grade and apply to both toms and hens with due consideration for age and sex characteristics)

Grade Factor	U. S. Grade AA	U. S. Grade A	U. S. Grade B	U. S. Grade C
Age	Young Old	Young Old	Young Old	Young Old
Quality of meat	Fine grain, soft Hard	Soft Hard	Fairly soft Hard	Coarse Hard
Fleshing	Fully fleshed and finished	Well fleshed, normally developed	Fairly well fleshed May be slightly lacking in breast development	Poorly fleshed
Breast shape	Plump, broad, flat across top and long	Moderately broad and long	May be slightly narrow	Narrow
Fat covering	Fully covered	Well covered	Fairly well covered	Poorly covered
Flesh over bones	Thick layer	Well covered	Fairly well covered	Poorly covered
Bleeding	Fully bled	Well bled	Fairly well bled	Poorly bled
Dressing	Extra well dressed	Well dressed	Fairly well dressed	Poorly dressed
Pinfeathers	None	None protruding, practically free of nonprotruding	None protruding. Few scattered nonprotruding permitted	None protruding. Numerous nonprotruding permitted
Abrasions and discolorations	Few very slight permitted. None on breast	Few slight permitted. Breast practically free	Fairly numerous permitted	Permitted
Blue back pigmentation	None	Tail only	Tail to hips only	Any amount permitted
Open tears	None	Less than 3 inches on back and wings permitted	Permitted on back and wings and one tear under 3 inches on breast and legs	Permitted
Sown skin	None	None	None	None
Broken bones	None above the wing tip	None above the wing tip	One nonprotruding broken wing or leg bone permitted	Nonprotruding broken bones permitted if not accompanied by bruise or blood clot
Disjointed bones	None	One disjointed wing or leg permitted if no appreciable bruise or blood clot	Two disjointed bones permitted if no bruise or blood clot	Disjointed bones permitted if no bruise or blood clot
Bruises	None	None	None	None

TABLE 20-3. U. S. STANDARDS FOR GRADES OF DRESSED DUCKS, GEESE, GUINEAS AND SQUABS

Kind	U. S. Grade	Quality Specifications for Individual Birds
Ducks	U. S. Grade A (Young)	Young, full-fleshed bird of either sex, well dressed, free from deformities.
	U. S. Grade B (Young)	Young, well-fleshed, well-dressed bird of either sex, free from deformities; or full-fleshed bird that shows slight deformities, blood spots or slight dressing defects.
	U. S. Grade A (Old)	Mature, full-fleshed bird of either sex, well-dressed, free from deformities.
	U. S. Grade B (Old)	Mature, well-fleshed, well-dressed bird of either sex, free from deformities; or full-fleshed bird that shows slight deformities, blood spots or slight dressing defects.
	U. S. Grade C	Edible bird of any age and of either sex inferior to U. S. Grade B.
Geese	U. S. Grade A	Full-fleshed, fat bird of any age and of either sex, free from blood spots, bruises or dressing defects or deformities.
	U. S. Grade B	Well-fleshed, well-dressed bird of any age and of either sex, free from deformities; or full-fleshed bird that shows slight deformities or slight dressing defects.
	U. S. Grade C	Edible bird of any age and of either sex inferior to U. S. Grade B.
Guineas	U. S. Grade A (Young)	Young, well-fleshed, well-dressed bird of either sex, free from deformities; must be plucked and bled.
	U. S. Grade B (Young)	Young, poorly fleshed, well-dressed bird of either sex or well-fleshed bird that shows slight deformities or slight dressing defects. Must be plucked and bled.
	U. S. Grade A (Old)	Mature, well-fleshed, well-dressed bird of either sex, free from deformities; must be plucked and bled.
	U. S. Grade B (Old)	Mature, poorly fleshed, well-dressed bird; or well-fleshed bird that shows slight deformities or slight dressing defects; must be plucked and bled.
	U. S. Grade C	Edible bird of any age and of either sex, inferior to U. S. Grade B.
Squabs	U. S. Grade A	Well-fleshed, well-dressed bird of light colored skin and flesh, well covered with fat.
	U. S. Grade B	Well-fleshed, poorly dressed bird of light colored skin and flesh, or thin, dark colored, well-dressed bird.
	U. S. Grade C	Edible bird inferior to U. S. Grade B.

TABLE 20-4. COMPOSITION OF MEATS, FISH, AND POULTRY PRODUCTS *
(Edible Portion)

Name	Percentage by Weight							Parts per Million		Alkaline (+) or Acid (−) Effect	Calories per 100 Grams	Vitamin Content per 100 Grams †			
	Protein	Carbohydrate	Fat	Crude Fiber	Ash	Calcium	Phosphorus	Iron	Copper			A	B_1	C	B_2
Bacon (lean)	12.2	1.4	53.0	...	4.7	0.006	0.108	24.0	5.0	− 4.8	531	0	270	0	150
Beef brains	10.5	1.4	8.8	...	1.4	.016	.340	53.0	2.1	−20.7	127	54	170	19	300
Beef, chuck (good grade)	17.6	0.0	22.0	...	0.8	.012	.220	30.0	1.0	−11.0	268	21	84	..	270
Beef, chuck (common grade)	19.2	0.0	9.0	..	0.9	....	.....	.	.	..	..	....	....	..	....
Beef, corned (medium)	15.8	0.0	25.0	...	5.0	.013	.119	98.0	..	−10.0	288	..	....	..	....
Beef, corned (very lean)	19.4	0.0	8 0	...	6.2	..	...	....	....	..	...	..	....	..	....
Beef heart (lean)	16.9	0.7	3.7	...	1.1	.018	.268	35.3	...	− 9.1	104	200	660	4	750
Beef kidney	15.0	0.9	8.1	...	1.1	.009	.182	41.0	1.1	− 8.5	137	1100	400	11	2000
Beef liver	19.7	6.0	3.2	...	1.4	.003	.420	79.0	21.5	−10.5	132	9000	270	41	2500
Beef, loin (good grade)	15.6	0.0	31.0	...	0.8	.012	.216	30.0	1.0	−11.1	341	21	210	2	350
Beef, loin (common grade)	18.6	0.0	16.0	...	1.0	....	.....	....	...	....	...	....	...	..	....
Beef steak (good grade)	18.7	1.4	17.0	...	0.9	.012	.216	30.0	1.0	−10.6	233	21	210	2	350
Beef steak (common grade)	19.7	0.0	8.0	...	1.0	....	..	...	...	....	...	....	....	..	....
Beef sweetbreads (good grade)	10.3	0.0	41.0	...	0.9	.014	.595	16.0	...	−11.7	410	....	330	..	670
Beef sweetbreads (common grade)	14.4	0.0	19.0	...	1.5	.....	.....	....	....	....	...	....	....	..	....
Beef tongue (good grade)	15.7	0.4	18.0	...	0.8	.008	.200	60.0	....	−10.6	226	....	280	0	220
Beef tongue (common grade)	17.4	0.4	11.0	...	0.9	.....	.....	....	....	....	...	....	....	..	....
Bluefish	20.5	0.0	4.0	...	1.2	.023	.236	6.0	2.3	− 9.0	113	0	..	0	....
Bologna	14.4	0.0	17.8	...	3.0	.003	.068	23.4	....	− 8.5	218	....	520	0	....
Chicken	21.1	0.0	4.5	...	1.1	.012	.232	32.0	3.5	−13.9	125	....	120	4	170
Clams	12.8	3.4	1.4	...	2.1	.109	.099	42.5	....	....	77	200	20	30	15
Codfish	16.5	0.0	0.4	...	1.2	.012	.120	6.0	5.5	− 8.4	70	10	120	0	160
Crabs	16.1	0.6	1.6	..	1.7	.017	.181	61.0	5.7	−39.5	81	....	140	13	350
Duck	21.4	0.0	8.2	.	1.2	.010	.200	23.0	5.0	−24.4	159	....	360	8	....

Egg white	10.8	0.8	0.0	.	0.6	.015	.014	1.0	0.7	− 5.2	46	[illegible]	0	0	250
Egg yolk	16.3	0.7	[illegible].9	.	1.7	.137	.524	86.0	4.0	−27.0	355	2800	420	0	400
Eggs	12.8	0.7	11.5	. .	1.0	.067	.180	30.0	2.3	−11.0	158	1000	150	0	300
Frankfurters	14.1	0.0	20.8	...	2.8	.007	.117	16.0	....	− 9.3	244	....	....	..	....
Gelatin, dried	85.6	0.0	0.1	...	1.3	.453	.234	. . .	....	−	343	0	0	0	0
Goose	22.3	0.0	7.1	...	1.1	.009	.175	24.0	3.3	− 7.8	153	....	150	13	....
Haddock	17.2	0.0	0.3	...	1.2	.018	.197	5.0	2.8	−12.0	72	7	120	0	160
Halibut	18.6	0.0	5.2	...	1.0	.020	.200	10.0	2.3	− 9.3	121	....	120	0	180
Ham (fat)	14.6	0.3	44.0	...	5.1	.012	.215	30.0	....	− 9.5	456	....	1400	0	250
Ham (lean)	19.5	0.3	25.0	. .	5.8	....	.....	..	....	.....	...	....	...	..	....
Herring	19.0	0.0	6.7	...	1.6	.021	.224	6.0	2.8	− 9.0	136	200	120	0	1000
Lamb chops	21.7	0.7	29.9	. .	1.3	.021	.180	33.0	4.2	− 9.7	359	0	250	0	280
Lobster	16.2	0.5	1.9	.	2.2	.018	.188	9.0	7.0	−38.4	84	. .	150	5	130
Mackerel	18.7	0.0	12.0	.	1.2	.011	.273	10.0	3.0	−11.0	183	150	120	0	660
Mince meat	6.7	60.2	1.4	...	4.0	.085	.175	30.0	0.8	+12.2	280	...	..	0	....
Mutton, leg	19.8	0.0	12.4	...	1.2	.010	.270	30 0	4.0	− 9.6	191	0	360	3	280
Oysters	9.8	5.9	2.0	.	2.0	.032	.155	45.0	30.0	−22.5	81	210	200	3	460
Pork chops (good grade)	14.8	0.0	32.0	..	0.8	.010	.180	25.0	3.1	− 8.0	347	....	1400	2	240
Pork chops (common grade)	17.9	0.0	18.0	..	1.0	.....	....	. .	....	. .	...	....	...	...	....
Pork sausage	10.8	0.0	44.8	.	2.1	.007	.116	16.3	1.2	− 7.5	446	....	450	0	240
Rabbit	20.8	0.0	10.2	...	1.1	.019	.183	5.6	2.0	−14.8	175	....	33	4	60
Salmon	17.4	0.0	16.5	...	1.0	.025	.250	12.0	2.0	−10.8	218	270	120	9	220
Sardines in oil	25.7	1.2	11.0	. .	4 7	.340	.390	20.0	0.4	−11.3	207	140	90	0	620
Scallops	14.8	3.4	0.1	. .	1.4	.115	.338	30.0	2.3	−36.2	74	0	...	3	....
Shrimp	25.4	0.2	1 0	. .	2.6	.096	.292	27.0	4.3	− 1.6	111	....	90	3	160
Tripe	19.1	0.0	2.0	. .	0.4	.127	.132	16.0	. ..	− 8.1	94	....	0	..	....
Tuna in oil	24.2	0.0	10.8	...	2.0	.030	.300	15.0	5.0	−	194	200	....	..	....
Turkey	24.0	0.0	6.7	.	1.1	.030	.420	45.0	1.8	−11.0	156	....	150	0	....
Veal chops (good grade)	18.6	0.0	15.0	. .	1.0	.012	.220	30.0	2.5	−13.5	209	....	270	..	240
Veal chops (common grade)	19.7	0.0	8.0	. .	1.0	.....	. ..	....	....	....	...	....	....	..	....
Veal cutlet (good grade)	19.1	0.0	12.0	...	1.0	.015	.228	30.0	2.5	− 9.8	184	0	120	0	300
Veal cutlet (common grade)	19.9	0.0	6.0	...	1.1	.....	.....	....	....	....	...	....	....	..	....
Whitefish	22.9	0.0	6.5	...	1.6	.025	.263	4.2	1.9	−10.0	150	....	90	..	....

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* Values mostly from Nutritional Charts, 1942, H. J. Heinz Co., by permission.

† Vitamin A is expressed in International units, vitamin B_1 and B_2 in micrograms and vitamin C in milligrams per 100 grams or 100 ml. of food.

TABLE 20-5. POUNDS OF FROZEN POULTRY IN STORAGE IN THE U. S. ON DATE INDICATED

Month	1944	5-Yr. Average
Jan. 1	225,843,000	184,290,000
Feb. 1	239,800,000	168,005,000
Mar. 1	220,404,000	141,026,000
Apr. 1	168,036,000	106,218,000
May 1	129,988,000	77,431,000
June 1	122,733,000	66,468,000
July 1	131,083,000	67,991,000
Aug. 1	142,075,000	69,348,000
Sept. 1	160,002,000	74,474,000
Oct. 1	187,534,000	90,499,000
Nov. 1	246,856,000	124,541,000
Dec. 1	270,068,000	170,163,000

TABLE 20-6. LATENT HEATS AND PERCENTAGES OF WATER AND SOLIDS IN MEATS, FISH AND POULTRY PRODUCTS

Product	% Solids	% Water	Latent Heat, Btu
Bacon	71.3	28.7	41.0
Beef brains	22.1	77.9	110.0
Beef chuck, high grade	40.4	59.6	85.5
Beef chuck, low grade	29.1	70.9	101.5
Beef, corned, medium	45.8	54.2	78.0
Beef, corned, very lean	33.6	66.4	95.0
Beef heart	22.4	77.6	111.0
Beef kidney	25.1	74.9	107.0
Beef liver	30.3	69.7	100.0
Beef loin, good	47.4	52.6	75.5
Beef loin, common	35.6	64.4	92.5
Beef steak, good	38.0	62.0	89.0
Beef steak, common	28.7	71.3	102.0
Beef sweetbreads, good	52.2	47.8	58.5
Beef sweetbreads, common	34.9	65.1	93.0
Beef tongue, good	34.9	65.1	93.0
Beef tongue, common	29.7	70.3	101.0
Bluefish	25.7	74.3	106.5
Bologna	35.2	64.8	92.5
Chicken	26.6	73.4	106.0
Clams	19.7	80.3	115.0
Codfish	18.1	81.9	117.0
Crabs	20.0	80.0	115.0
Duck	30.8	69.2	99.5
Egg whites	12.2	87.8	126.0
Egg yolks	50.6	49.4	71.0
Eggs	26.0	74.0	106.0
Frankfurters	37.7	62.3	89.5
Gelatin (dry)	87.0	13.0	18.5
Goose	30.5	69.5	100.0
Haddock	18.7	81.3	116.5
Halibut	24.8	75.2	108.0
Ham (fat)	64.0	36.0	52.0
Ham (lean)	50.6	49.4	71.0
Herring	27.3	72.7	104.0
Lamb chops	53.6	46.4	66.5
Lobster	20.8	79.2	113.5
Mackerel	31.9	68.1	98.0
Mince meat	72.3	27.7	39.5
Mutton leg	33.4	66.6	95.5
Oysters	19.7	80.3	115.5
Pork chops (high grade)	47.6	52.4	75.5
Pork chops (common)	36.9	63.1	91.0
Pork sausage	57.7	42.3	61.0
Rabbit	32.1	67.9	100.0
Salmon	34.9	65.1	93.0
Sardines in oil	42.6	57.4	82.5
Scallops	19.7	80.3	115.5
Shrimp	29.2	70.8	101.5
Tuna in oil	37.0	63.0	90.0
Turkey	31.8	68.2	98.0
Veal chops (high grade)	34.6	65.4	94.0
Veal chops (common)	28.7	71.3	103.0
Veal cutlets (high grade)	32.1	67.9	97.0
Veal cutlets (common)	27.0	73.0	104.0
Whitefish	31.0	69.0	99.0

TABLE 20-7. CASES OF SHELL EGGS IN STORAGE IN THE U. S. ON DATE INDICATED

Month	1944	5-Yr. Average
Jan. 1	667,000	454,000
Feb. 1	761,000	207,000
Mar. 1	1,976,000	407,000
Apr. 1	4,416,000	1,606,000
May 1	6,987,000	4,102,000
June 1	9,659,000	6,470,000
July 1	11,354,000	7,545,000
Aug. 1	9,770,000	7,534,000
Sept. 1	7,680,000	6,850,000
Oct. 1	5,463,000	5,670,000
Nov. 1	2,945,000	3,726,000
Dec. 1	1,048,000	1,634,000

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SECTION XXI

REFRIGERATION IN THE DAIRY INDUSTRY

Physical Properties of Milk:

Temperature as it comes from cow, degrees F.	95–98
Specific heat (whole milk):	
Above freezing	0.93
Below freezing	0.47
Latent heat of fusion, Btu/lb.	125
Water content (average), per cent	87.4
Specific gravity (average at 60° F.)	1.032
Density, lbs./gal. (average)	8.6
Freezing point, °F.	31.09
Pasteurizing temperature, °F., 30 min.	142–145
Pasteurizing temperature, °F., 30 sec.	153–160

No class of farm products requires more care in handling and marketing than milk. From the time the milk is taken from the cow until it is consumed, it must be properly protected, particularly against dangerous bacteria. Warm milk is ideal for the propagation of bacteria and unless some precautions are taken to check their rapid growth the milk will soon become unfit for human consumption. This section is devoted to a discussion of the part refrigeration plays in the transportation, handling, processing, and storage of milk and milk products.

As milk and cream are cooled, bacterial rates of increase are diminished accordingly until at a critical point for milk, around 50° F., or 40° F. for cream, multiplication of bacteria is so slow that at or below these temperatures reasonably long periods of storage are practical.

Bacterial growth is most rapid at temperatures of from 70° F. to 100° F., and while such growth practically stops at freezing, some few bacteria continue to develop slowly even at this temperature. When temperature conditions again become favorable, normal activity is resumed. Actual freezing of milk must of course be guarded against because of resulting changes in physical characteristics and greatly impaired quality.

On many farms the time between cream shipments is close to a week. The critical cooling and storage temperature under such conditions is around 33° F.

Major sources of contamination in order of their general importance are (1) unsterilized or dirty utensils (including milking machines and cream separators); (2) foreign material or dirt from the cow's flanks, udder, etc.; and (3) contamination from insects, the stable air, and the foremilk from the cow's udder.

Fresh milk which is cooled to 50° F. or less within 3 or 4 hrs. (precooling or stirring is not necessary) and stored at a temperature of 35° F. to 40° F. will not increase appreciably in bacterial content during the first 12 hrs. The greater care required after this time is apparently due in part to the gradual impairment of the germicidal qualities found in freshly drawn milk. However, even low-count milk will sour or even clabber within a very few hours if allowed to stand at high temperatures (70° F. to 100° F.). Very little milk need be held by the producer for more than 12 hrs., or, at most, 24 hrs.

The experiments of Conn demonstrated that with milk stored for 24 hrs. at 50° F., the bacteria multiplied only five times, whereas with other samples of the same supply stored for 24 hrs. at 70° F. the bacteria multiplied seven hundred and fifty times.

Refrigerated storage for milk may be either of the "wet" or "dry" type. The type used at any dairy or plant will be determined by the service to be rendered.

Wet storage consists in placing cans of milk or cream in a tank of chilled water, or in first passing the milk over a surface-type cooler and then placing the cans in the water for storage. The wet-storage type of equipment is particularly suited for small wholesale dairies. Available data indicate that agitation of the water bath is necessary to cool the milk or cream rapidly.

It is apparent that several different schemes may be used for cooling and storing milk in wet-storage coolers. The scheme selected will often be determined by the local board of health regulations. Some of the schemes used consist of the following:

(1) Placing warm milk in cans in the chilled water bath.
    (a) The only agitation of the water bath is here obtained from the convection currents, or
    (b) Chilling is effected by mechanically agitating the water bath to lessen the cooling time.
(2) Passing the warm milk over a surface cooler before placing in cans and storing in the water bath. The chilled water from the cooler is used to cool the surface cooler.

(3) Same as (2) except that the surface cooler is cooled with spring or well water.

(4) Same as (2) except that the upper half of the surface cooler is cooled with spring or well water and the lower half with chilled water from the cooler.

Dry type storage overcomes two big disadvantages of the wet-storage systems in that little or no contamination is possible and any type of containers may be stored. Dry storage consists of an insulated box or room in which the air is the secondary refrigerant. If the quantity of products to be stored is sufficiently large, the storage will be of the walk-in type, otherwise a box or chest type storage unit will be sufficient. Dry storage may be refrigerated by either brine or direct expansion of the primary refrigerant.

To illustrate the possibilities of milk storage and sanitation, American dairies exhibited raw milk at the Paris Exposition of France and maintained weekly delivery service from the United States to the exhibit room in Paris.

Cream and Butter. Refrigeration plays a very important part in the plant where cream is made into butter. The importance of butter making is shown by the fact that approximately 45%, or 55,750,000,000 lbs. of the milk marketed annually in this country, goes into butter. The storage of butter is important in the milk industry because it tends to stabilize the butter market throughout the year. In the spring and summer months when the production of milk is highest, a large amount of butter is made and stored. If the butter is to be used in a short time the storage temperature may be as high as 28° F. to 30° F. However, if butter is to be stored for more than one month or six weeks the temperature should be 0° F. The relative humidity in butter storage rooms should be approximately 80%. The average specific heat of butter is 0.55.

The method of handling cream in the plant will depend upon the kind of butter being made. If sweet cream is to be made, the pasteurized cream is cooled to 40° F.–45° F. and held from 3 hrs. to overnight. The cream is then churned. In this process there is no ripening of the cream, since the temperature is low.

If ripened cream butter is to be made, the pasteurized cream is cooled to 65° F. and about 5% lactic "starter" is added. The cream is then held for 1 to 5 hrs. for the desired acidity to be reached. The temperature is then reduced to 45° F. and is held until churned.

TABLE 21-1. GROWTH OF BACTERIA IN MILK
(Based on Initial Bacteria Count)

Holding Temperature, °F.	Initial Bacteria Count, cc.	4 Hrs.	8 Hrs.	15 Hrs.
70	5,000	7,000	15,000	140,000
	50,000	100,000	1,000,000	2,100,000
	500,000	700,000	2,000,000	9,000,000
60	5,000	6,000	8,000	11,000
	50,000	60,000	80,000	1,200,000
	500,000	540,000	800,000	2,800,000
50	5,000	5,500	5,500	7,000
	50,000	48,000	52,000	80,000
	500,000	550,000	580,000	700,000
40	5,000	4,700	4,000	3,000
	50,000	46,000	40,000	36,000
	500,000	500,000	500,000	440,000

TABLE 21-2. MILK CANS

	5 Gal.	8 Gal.	10 Gal.
Weight (lbs.)	14	18	22
Specific heat	0.117	0.117	0.117
Diameter (in.)	11	13	13
Height (in.)	20	23	25

TABLE 21-3. MILK BOTTLE CRATES

	Quart	Pint	Half pint
Weight (lbs.)	16	14	11
Specific heat	0.65	0.65	0.65
Number bottles	12	20	30
Length (in.)	18½	18½	18½
Width (in.)	14½	14½	14½
Height (in.)	10½	8½	6¾

DEFINITIONS OF MILK GRADES BASED ON NEW YORK STATE SANITARY CODE

Pasteurized—Certified. Milk so produced, handled and cooled as to give before pasteurization a bacterial count of not more than [illegible]0,000 per cc. and previous to delivery after pasteurization of not more than 500 per cc.

Pasteurized—Grade A. Milk so produced, handled and cooled as to give before pasteurization a bacterial count of not more than 100,000 per cc. and previous to delivery after pasteurization of not more than 30,000 per cc.

Pasteurized—Grade B. Milk so produced, handled and cooled as to give before pasteurization a bacterial count of not more than 300,000 per cc. and previous to delivery after pasteurization of not more than 50,000 per cc.

Grade A Raw. Milk so produced, handled and cooled as to give at any time previous to delivery to the customer a bacterial count of not more than 30,000 per cc. Such milk must be delivered within 36 hrs. after milking.

TABLE 21–4. TYPICAL MINIMUM STATE STANDARDS FOR MILK

State	Per Cent Fat	Per Cent Other Solids
Arizona	3.25	8.5
California	3.00	8.5
Illinois	3.00	8.5
Mississippi	3.00	8.5
Missouri	3.25	8.5
North Carolina	3.25	8.5
Oklahoma	3.50	8.5
Tennessee	3.50	8.5
Texas	3.25	8.5
Wisconsin	3.00	8.5

In general the southern requirements of butter fat are somewhat higher than those of the northern areas. This may be explained in part by the larger number of Jersey cattle in the warmer climates. The heavy milk producing cows, like the Holstein, do not adapt themselves to hot climatic conditions.

TABLE 21-5. MILK BOTTLE CHARACTERISTICS

	Quart	Pint	Half Pint
Weight (lbs.)	2	1	0.75
Specific heat	0.2	0.2	0.2
Diameter (in.)	4	3¼	2¾
Height (in.)	9¼	8½	6¾

TABLE 21-6. COMPOSITION OF MILK

Animal	Specific Gravity	Water	Casein	Albumen	Fat	Sugar	Ash
Man	1.030	87.6	0.80	1.21	3.75	6.37	0.30
Cow	1.032	87.3	2.88	0.51	3.68	4.94	0.72
Goat	1.031	86.9	2.87	0.89	4.07	4.64	0.85

TABLE 21-7. LATENT HEATS AND PER CENTS OF WATER IN DAIRY PRODUCTS

Product	% Solids	% Water	Latent Heat, Btu
Butter	88.1	11.9	17.0
Buttermilk	9.5	90.5	130.0
Cheese, American	61.0	39.0	56.0
Cheese, Roquefort	62.6	37.4	53.5
Cheese, Swiss	66.0	34.0	49.0
Cream, sour	26.0	74.0	106.0
Cream, sweet	27.5	72.5	104.0
Ice cream	38.0	62.0	89.0
Margarine	84.5	15.5	22.0
Milk, condensed	73.0	27.0	38.5
Milk, evaporated	26.3	73.7	106.0
Milk, goat	13.0	87.0	125.0
Milk, skim	9.5	90.5	129.0
Milk, whole	13.0	87.0	125.0

The Freezing of Milk. If milk is frozen slowly there is the likelihood of a much greater separation of the water than if frozen quickly. Milk as it freezes undergoes physical changes and the slower it freezes the more opportunity is given for the changes to occur. Milk frozen and thawed will not be exactly the same as raw unfrozen milk, but the freezing procedure can be controlled to preserve milk and give a product so nearly equal to raw milk that it is commercially desirable and acceptable.

TABLE 21-8. POUNDS OF CREAMERY BUTTER IN STORAGE IN THE U. S. ON DATE INDICATED

Month	1944	5-Yr. Average
Jan. 1	154,364,000	73,029,000
Feb. 1	129,952,000	53,794,000
Mar. 1	107,467,000	40,726,000
Apr. 1	82,038,000	31,698,000
May 1	69,533,000	33,125,000
June 1	69,659,000	62,835,000
July 1	106,922,000	121,502,000
Aug. 1	138,168,000	165,271,000
Sept. 1	138,378,000	178,212,000
Oct. 1	139,938,000	168,347,000
Nov. 1	123,985,000	143,613,000
Dec. 1	91,104,000	106,910,000

TABLE 21-9. POUNDS OF AMERICAN CHEESE IN STORAGE IN THE U. S. ON DATE INDICATED

Month	1944	5-Yr. Average
Jan. 1	150,784,000	117,491,000
Feb. 1	142,370,000	102,056,000
Mar. 1	144,770,000	91,842,000
Apr. 1	121,672,000	91,777,000
May 1	123,364,000	94,262,000
June 1	137,828,000	104,435,000
July 1	166,802,000	129,072,000
Aug. 1	189,636,000	153,371,000
Sept. 1	186,392,000	159,856,000
Oct. 1	165,975,000	157,951,000
Nov. 1	147,581,000	148,051,000
Dec. 1	137,658,000	136,023,000

Ice Cream

Physical Properties of Ice Cream (Average Values):

Specific heat:	
Above freezing	0.80
Below freezing	0.45
Latent heat of fusion (Btu/lb.)	90.0
Density of mix (lbs./gal.)	9.0
Density of ice cream, 85% over-run (lbs./gal.)	4.9

Ice Cream Making. Ice cream is one of the best-known foods today and yet it is still listed as a confection.

The methods used in different plants manufacturing ice cream may differ slightly but the "flow" through a modern plant is about as follows: The various ingredients are mixed and proportioned at the pasteurizer and, after processing, the entire mix is passed through a homogenizer and then over a surface cooler. The mix is held at from 35° F. to 40° F. until passed into the freezer. After freezing, the mix flows into cans which are placed in the hardening room. The ice cream is kept in the hardening room until ready for delivery.

In passing through the homogenizer, the large fat globules are broken up to give the cream a smoother texture. It is necessary that the viscosity of the cream be increased along the line in order to obtain the proper overrun. Overrun refers to the increase in volume which occurs in the freezer. It is due in part to the expansion of the ingredients, but mainly to the inclusion of air by the whipping action of the dasher. The desired overrun of plain cream is not over 100%, and for fruit creams about 80%. Too little overrun will give a soggy, heavy cream, while too great an overrun will produce a fluffy, grainy cream.

The average refrigerant temperature in freezers is from 0° F. to 10° F. so as to cool the 40° mix as rapidly as possible to about 25° F. The cream is in a semi-solid state as it flows from the freezer. In most cases about one half of the actual freezing of ice cream occurs in the hardening room. Hardening rooms are held at from −10° F. to −5° F. About 18 to 24 hrs. are required to harden an ordinary gallon can of ice cream.

TABLE 21–10. FLAVOR ANALYSIS OF ICE CREAM CONSUMPTION IN THE U. S. A. (Ice Cream Mfg. Bulletin H2)

Flavor	Per Cent Used
Vanilla	48.46
Chocolate	16.78
Strawberry	8.27
Peach	2.27
Cherry	1.98
Maple	1.62
Pineapple	1.50
Burnt Almond	1.18
Black Walnut	0.50
All others	17.44

TABLE 21–11. STATES REQUIRING THE PASTEURIZING OF DAIRY PRODUCTS USED IN THE MANUFACTURE OF ICE CREAM

State	Temperatures Specified, °F.
Arkansas	145 for 25 min. 150 for 20 min. 170 flash
California	140–145 for 30 min.
Connecticut	142 for 30 min.
District of Columbia	142 for 30 min.
Florida	145 for 30 min. 185 flash
Georgia	145 for 30 min.
Indiana	145 for 30 min. 165 for 30 min.
Iowa	145 for 25 min. 185 flash
Louisiana	145 for 25 min.*
Michigan	142 for 30 min.** 150 for 30 min.***
Mississippi	145 for 30 min.*
Nevada	140 for 25 min. 170 flash
Oregon	140 for 30 min. 180 flash
Tennessee	145 for 25 min. 150 for 20 min. 170 flash

* Requires pasteurization of ice cream mix.

** Ingredients without sugar. *** Complete mix.

TABLE 21–12. STATE BUTTERFAT AND MILK SOLIDS STANDARDS FOR PLAIN, FRUIT AND NUT ICE CREAM *

(T.S. = Total Solids; M.S. = Milk Solids (including fat); M.S.N.F. = Milk Solids Not Fat)

State	Plain Ice Cream		Fruit and Nut Ice Cream	
	Fat, %	Solids, %	Fat, %	Solids, %
Alabama	10	33 T.S.	8	33 T.S.
Arizona	10	30 T.S.	8	30 T.S.
Arkansas	8	32 T.S.	6	32 T.S.
California	10	......	8	....
Colorado	10	......	10	....
Connecticut	8	......	6	....
Delaware	12	......	10	....
District of Columbia	8	....	8	....
Florida	10	.	8	....
Georgia	10	20 M.S. 33 T.S.	10	20 M.S. 33 T.S.
Idaho	14	....	12	......
Illinois	8	. .	8	....
Indiana	8	18 M.S.	8	18 M.S.
Iowa	12	. . .	10	....
Kansas	10	20 M.S. 33 T.S.	10	20 M.S. 33 T.S.
Kentucky	10	18 M.S.	..	......
Louisiana	10	20 M.S.	8	18 M.S.
Maine	14	......	12	......
Maryland	10	....	8	....
Massachusetts	10	18½ M.S.	8	16½ M.S.
Michigan	12	....	10	....
Minnesota	12	....	10	....
Mississippi	10	. ..	8	....
Missouri	8	. .	8	....
Montana	10	33 T.S.	9	33 T.S.
Nebraska	14	..	12	.....
Nevada	14	....	12	....
New Hampshire	14	....	12	....
New Jersey	8	...	6	....
New Mexico	..	.. ..	..	....
New York	8	18 M.S.	8	18 M.S.
North Carolina	8	. . .	8	....
North Dakota	12	. ...	10	....
Ohio	8	.. ..	8	....
Oklahoma	10	... ..	10	....
Oregon	12	20 M.S.	10	18 M.S.
Pennsylvania	10	......	8	......
Rhode Island	8	.... .	8	....
South Carolina	.	. .		....
South Dakota	12	.... .	10	....
Tennessee	8	18 M.S.	6	16 M.S.
Texas	8	......	6	.... .
Utah	14	30 T.S.	12	28 T.S.
Vermont	14	....	12	....
Virginia	10	33 T.S.	8	....
Washington	10	20 M.S.	10	20 M.S.
West Virginia	8	10 M.S. N.F.	..	....
Wisconsin	13	....	11	......
Wyoming	10	....	10	....

* Bureau of Service and Statistics, International Assn. of Ice Cream Mfrs.

TABLE 21–13. COMPOSITION OF DAIRY PRODUCTS *

Name	Percentage by Weight							Parts per Million		Alkaline (+) or Acid (−) Effect	Calories per 100 Grams	Vitamin Content per 100 Grams †			
	Protein	Carbohydrate	Fat	Crude Fiber	Ash	Calcium	Phosphorus	Iron	Copper			A	B_1	C	B_2
Butter	0.6	0.4	81.0	. .	2.5	0.015	0.017	2.0	...	0.0	733	2400	0–120	0	8
Buttermilk	3.5	5.0	0.2	...	0.8	.105	.097	2.5	0.5	+ 2.2	36	0	42	0	155
Cheese, American	23.9	1.7	32.3	...	3.1	.930	.683	13.8	1.8	− 5.4	393	2000	42	0	450
Cheese, Cheddar	22.3	1.7	30.2	...	5.8	.710	.682	12.5	0.5	− 5.0	368	2000	42	0	600
Cheese, Cottage	12.5	4.3	0.8	...	1.7	.077	.374	1.1	...	− 4.5	74	110	20	0	....
Cheese, Cream	7.1	1.7	36.9	. .	1.0	.635	.528	13.0	0.4	− 3.4	367	2200	30	0.9	150
Cheese, Roquefort	21.7	1.4	33.2	...	6.3	.721	.525	9.8	..	+	391	4000	30	0	....
Cheese, Swiss	28.6	1.9	31.3	...	4.2	1.050	.845	12.5	1.3	− 5.0	404	2700	30	0	370
Cream, sour	2.5	4.5	18.5	...	0.5	.090	.080	2.2	1.5	−	195	2200	60	1.0	350
Cream, sweet	2.9	4.0	20.0	...	0.6	.090	.080	2.2	1.5	0.0	208	1600	60	1.0	350
Ice Cream	3.9	20.3	13.0	...	0.8	.150	.120	3.6	0.3	+ 0.2	214	900	24	1.0	50
Margarine (average fortified)	0.6	0.4	81.0	...	2.5	.004	.012	3.0	0.4	0.0	733	3000	0	0	0
Milk, condensed (sweetened)	8.1	54.8	8.4	...	1.7	.300	.235	6.0	1.0	+ 5.2	327	280	72	1.0	350
Milk, dried skim	35.6	52.0	1.0	...	7.9	1.240	.960	35.0	5.7	+18.0	359	140	380	0	2400
Milk, evaporated	7.0	9.9	7.9	...	1.5	.250	.200	5.3	1.2	+ 5.1	139	460	60	1.5	320
Milk, goat	3.3	4.8	4.2	...	0.7	.123	.103	2.0	0.2	+	70	170	60	1.5	80
Milk, human	1.4	7.2	3.7	...	0.2	.034	.015	1.8	0.6	+	63	350	30	6.0	65
Milk, skim	3.5	5.0	0.2	...	0.8	.122	.096	2.5	0.2	+ 2.4	36	17	42	1.4	160
Milk, whole (pasteurized)	3.5	4.9	3.9	...	0.7	.120	.093	2.4	0.2	+ 2.3	69	170	36	0.7	210
Whey, dried	13.0	74.5	0.5	...	8.5	.572	.524	7.0	...	+	355	...	1100	0	5900

* Values mostly from Nutritional Charts, 1942, H. J. Heinz Co., by permission.

† Vitamin A is expressed in International units, vitamin B_1 and B_2 in micrograms, and vitamin C in milligrams per 100 grams per 100 ml. of food.

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SECTION XXII

REFRIGERATION APPLIED TO AIR COOLING

Air for comfort cooling may be lowered in temperature by (1) passing it over water-cooled pipes, (2) exposing it to a cold-water spray, (3) delivering it through an evaporative cooling pad, (4) blowing it over ice, (5) blowing it over dry ice and, (6) passing the air over pipes refrigerated by primary or secondary refrigerants. In addition, cooling of rooms by storing cool night air by blowing it into the space at night and then closing the room for the daytime period can be included as another cooling procedure.

When air is cooled by blowing it over water-cooled pipes, or by blowing it over ice or dry ice, or by passing it over refrigerated pipes, some of the moisture in the air is condensed and thus there is a resultant lowering of the wet-bulb temperature as well as the dry bulb. When air is cooled by either the spray system or the evaporative cooling process, the wet bulb may be increased somewhat by the addition of the vapor. Thus, the first group may decidedly lower the humidity and the effective temperature. The spray and the evaporative process seldom lower the humidity and may increase it.

Where very dry air exists, the spray and the evaporative systems can be successfully used by passing only a portion of the air over the cooling sprays or pads, then reuniting this portion with some of the available atmospheric dry air. The resultant air emerges with a lowered dry bulb, and, although the wet bulb may have increased, the effective temperature will be decidedly lower. In dry areas, evaporative cooling is very acceptable. In areas where the air is very humid the use of the refrigerated or the water-cooled coils is more effective.

Ice Cooling. The cooling of air by ice has been successfully used in Pullman cars, restaurants, theaters, auditoriums and churches. It has been less successful in the home. The criticism made usually is that the use of ice for cooling the home is faulty because the periods required for home refrigeration or cooling are more continuous than those in most other fields. This argument is not so valid in light of the experiences of the American Railroad Association in cooling Pullman and dining cars.

The principal reasons for the failure of ice to attract the home-owner are: (1) there has not been a concerted effort on the part of the ice industry to put their resources behind a home ice-cooling program, (2) no attractive system of snapping on and off the ice-cooling system has been evolved for the home, and (3) no substantial group of technicians has been trained to sell and service ice air conditioning on a national scale.

Ice has an advantage over all other types of cooling mediums except dry ice in that a larger refrigeration capacity can be released to the room in a short time from a relatively small amount of storage space as compared with any other system. If a 3-ton ice storage were connected to adequate cooling surface it could successfully take care of a 3- or 4-hr. load of 25 tons of refrigeration, a load that would require a direct-expansion 25-ton refrigerant compressor.

Ice can be used to refrigerate the water for either the spray or the pipe system, or it may be used for cooling air by blowing the air directly over the ice blocks with no attempt being made to utilize the cooling capacity of the melted ice after it has become water.

Most of the units employing the principle of circulating air over the ice block are of the small portable cooler type where any attempt to utilize the ice water would too greatly complicate the unit. In operation, the circulated air strikes the surface of the ice block and this contact lowers the temperature of the air sufficiently to cause an immediate condensation of part of the contained moisture of the air. This moisture of condensation unites with the melting ice to maintain a very wet surface on the ice and this wetted surface effect increases the melting rate of the ice. These effects have been illustrated in a previous section of the Handbook.

The two systems that use ice in connection with the water are sometimes classified as the central pump system and the central fan system. In either case the ice is placed in a well-insulated tank in which it may be floated in the ice water or placed immediately above the water reservoir. In one case the air to be cooled is circulated over cooling coils through which the ice water is pumped, while in the second case the air to be cooled is circulated directly through the insulated ice tank by the necessary fans.

When the system is designed as a central pump unit, the circulating pump is connected to take part of the water directly from the bottom of the ice tank and part is taken from the return water after it has passed through the cooling coils. In operation all of the water may be taken from the ice tank, or all recirculated from the cooling coils or part may come from each. This gives great adaptability in the temperature regulation of the air delivered to the rooms. That part of the water that is delivered back to the ice tank is sprayed over the ice blocks.

In the central fan system, the air is intimately mixed with the ice water by passing it through washing sprays. This operation eliminates some of the odors from the air and the air passing through the sprays acquires a wet-bulb and a dry-bulb temperature slightly above the cooling water temperature. The humidity would be too high and the temperature too low to circulate this air to the rooms without mixing it with some of the available dry atmospheric air. Thus, this system is better adapted to the areas of low humidity.

The success of the central fan or the central pump systems from an economic standpoint is largely dependent upon the insulation of the ice tank and the flexibility of the circulating water or air control. If the tank insulation is adequate and the controls on the circulating systems adapted to quickly cutting out the cooling service when it is not essential, then ice cooling can be most economical. If these two factors are not well recognized in the design, then the standby losses of the system will be very unfavorable.

In a well-insulated system, cooling with ice purchased at three or four dollars per ton should offer a very competitive balance sheet as against compression or absorption refrigeration. Most of the past failures of ice cooling have been caused by either poor design or unreliable delivery service. The thermodynamics of the ice system offers some very favorable considerations.

Mechanical Refrigeration Applied to Cooling. Mechanical refrigeration is utilized for cooling by:

(1) Central fan systems.
(2) Central liquid systems.
(3) Self-contained cooling units.

In *central fan systems* the air for the entire building is circulated to a central point, cooled, cleaned and dehumidified before being delivered through the ducts to the rooms. The cooling may be done by a spray type cooler and dehumidifier, by chilled brine or water coils or by direct expansion.

In *central liquid systems,* the unit coolers equipped with fans are distributed throughout the building. The chilled water, brine or refrigerant is circulated to the several units. This system requires less building space than the central fan system.

The *self-contained cooling unit* is the most popular of the mechanical refrigeration methods of cooling. The growth of the business in this class of cooling equipment is very rapid. The complete compressor unit, condenser and fan are included under the one cabinet head, with provision made for either air cooling or water cooling the condenser. Arrangements must be provided for discharging the condensing water or air to the outside. If the condensing unit is air cooled, the unit must be located adjacent to a window or other outlet to outside air. If the unit is water cooled, its location should be convenient to sources of water and drainage.

Water Vapor Refrigeration for Air Cooling. Water vapor refrigeration units are available in large and small units. Two types are manufactured. These are known commercially as the steam-jet and the centrifugal vacuum pump systems.

The water vapor cooling process was demonstrated nearly two centuries ago by Dr. William Cullen of Scotland. Its application is very recent.

When water is evaporated large quantities of heat are required. Under high vacuum conditions evaporation takes place at relatively low temperatures.

By spraying water into the vacuum, a part of it evaporates or flashes into vapor. The heat for this vaporization must be given up by the water that is not vaporized. Thus this evaporation chills the residual water usually to 40° F. or 50° F. This cold water is available for air conditioning.

If a steam ejector is used, the steam jet entrains the vapor and discharges it. If a centrifugal vacuum pump is used, it compresses the vapor and discharges it. In either case the principle is the same. The vacuum is produced which makes possible the boiling of the liquid at a low temperature. This boiling produces a vapor from part of the water. The steam jet or the centrifugal pump disposes of the vapor, and small circulating pumps distribute the chilled water to the cooling units.

For the steam-jet types, either low or high pressure steam can be used. The steam consumption is dependent upon (1) the steam pressure, (2) the condenser temperature, and (3) the degrees of cooling. For 50° F. water and 100° F. condenser temperature it requires approximately 40 lbs. of low pressure (10 lbs.) steam and 30 lbs. of high pressure (100 lbs.) steam per ton of refrigeration.

DETERMINATION OF COOLING REQUIREMENTS

In determining the amount of refrigerating or cooling necessary for maintaining a room at a comfortable temperature in hot weather, consideration must be given to offsetting the heat gain that is being contributed to the room space by:

(1) Conduction from the outside air caused by the lower temperature on the inside of the room.

(2) Sun effect and radiation through exposed windows, skylights, roofs and walls.

(3) Heat from lights, cooking equipment and power motors used within the space. Every kilowatt hour of electrical energy used releases 3413 Btu.

(4) Body heat from animal and human occupants housed within the space.

(5) Air changes and convection currents of air from the outside.

In addition it is necessary to lower the temperature of the air and material within the space to be cooled.

Heat Input Through Walls. The section of the Handbook devoted to heat transfer gave the fundamental data especially as applied to cold-storage construction. Many of the same values are applicable to general building construction. For convenience, supplementary data of built-up construction materials are given in Table 22-1. The nomenclature used in these tables and formulas is as follows:

U = over-all coefficient of heat transmission; the amount of heat expressed in Btu transmitted in one hour per square foot of wall, floor, roof, or ceiling for a difference in temperature of 1° F. between the air on the outside and that on the inside of wall, floor, roof, or ceiling.

k = thermal conductivity; the amount of heat expressed in Btu transmitted in one hour through one square foot of homogeneous material, one inch thick for a difference in temperature of 1° F. between the two surfaces of the material. The conductivity of any material depends on the structure of the material and its density. Heavy or dense materials, the weight of which per cubic foot is high, usually transmit more heat than light or less dense materials, the weight of which per cubic foot is low.

C = thermal conductance; the amount of heat expressed in Btu transmitted in one hour through one square foot of a nonhomogeneous material for the thickness or type under consideration for a difference in temperature of 1° F. between the two surfaces of the material. Conductance is generally used to designate the heat transmitted through such heterogeneous materials as plasterboard and hollow clay tile.

f = film or surface conductance; the amount of heat expressed in Btu transmitted by conduction, convection, and radiation from a surface to the air surrounding it, or vice versa, in one hour per square foot of the surface for a difference in temperature of 1° F. between the surface and the surrounding air. To differentiate between inside and outside wall (or floor, roof, or ceiling) surfaces, f_i is used to designate the inside film or surface conductance and f_0 the outside film or surface conductance.

a = thermal conductance of an air space; the amount of heat expressed in Btu transmitted by conduction, convection, and radiation in one hour through an area of one square foot of an air space for a temperature difference of 1° F. The conductance of an air space depends on the mean temperature, the width, the position, and the character of the materials enclosing it.

As an example in the application of these coefficients assume a wall with an over-all coefficient of U. Then

$$q = AU(t_0 - t) \tag{1}$$

where q = Btu per hour transmitted through the material of the wall, glass, roof, floor, etc.

A = area in square feet of wall, glass, roof, floor, or material taken from building plans or actually measured; use the hot surface dimensions in all cases.

$(t_0 - t)$ = temperature difference between outside and inside air.

TABLE 22-1. CONDUCTIVITIES (k) AND CONDUCTANCES (C) OF BUILDING MATERIALS. ASHVE GUIDE

(Conductivities are expressed in Btu per hr. per sq. ft. per degree F per in. thickness. Conductances are for the thickness or condition stated, not per inch)

MATERIAL	k	C	MATERIAL	k	C
Brick, common	5.0		Plaster (cement)	8.0	
Brick, face	9.2		Plaster board (⅜ in thick)		3.78
Concrete, typical	12.0		Plaster board (½ in thick)		2.82
Concrete blocks[1] (8 in)		1.0	Plaster (gypsum)	.3	
Concrete blocks[1] (12 in)		0.8	Plaster on metal lath (¾ in)		4.4
Glass	2.03		Plaster on wood lath (¾ in)		2.5
Hollow clay tile, 4 in		1.0	Roofing construction		
Hollow clay tile[2], 6 in		0.64	Asbestos shingles roof		6.0
Hollow clay tile[2], 8 in		0.60	Asphalt of composition roof		6.5
Hollow clay tile[2], 10 in		0.58	Built-up (⅜ in. thick) roof		3.53
Hollow clay tile[2], 12 in		0.40	Tar and gravel (¼ in. thick) roof		1.33
Insulation materials, ave.	0.27		Wood shingles		1.28
Aluminum foil[3]			Stone	12.5	
Corkboard	0.30		Stucco	12.0	
Cork, granulated	0.31		Tile or terrazzo	12.0	
Flaked gypsum (24 lb)	0.48		Woods		
Flexible, typical	0.27		Oak, typical	1.0	
Rigid insulation	0.33		Yellow pine or fir	0.8	
Rock wool	0.27				

[1] One air cell in the direction of heat flow.

[2] The 6-, 8-, and 10-in. figures are based on two cells in the direction of heat flow. The 12-in. hollow tile is based on three cells in the direction of heat flow.

[3] Air space, faced one side with bright aluminum foil, over ¾ in wide, C = 0.46; faced both sides, over ¾ in. wide, C = 0.41; air space divided into two with single curtain of aluminum foil, each space over ¾ in. wide, C = 0.22.

The over-all heat transmission coefficient is generally desired and may be determined from the following general equation.

$$U = \frac{1}{\frac{1}{f_1} + \frac{x_1}{k_1} + \frac{1}{C} + \frac{1}{a} + \frac{x_2}{k_2} + \frac{1}{f_0}} \qquad (2)$$

If the coefficients f_1, f_0, k, C and a, together with the thickness x of the homogeneous materials are known, the calculation for any type of wall construction may be readily made. Due to the wide variation in surface coefficients for different conditions their selection for each actual building becomes a matter of judgment. It will be assumed that there is a slight movement of air on both sides of a wall and that $f_1 = f_0 = 2.0$ as an average value for commonly used building materials. An average value of a, air space conductance coefficient for ¾ to 4 in. width of air space at a temperature of 80° F., may be taken as 1.25.

Example 1. Find the heat transmission coefficient for a 13-in. brick wall. How much heat would pass through 2000 ft. of this wall in Btu per hour, for an outside temperature of 100° F. and an inside temperature of 30° F.?

Note: Refer to Table 22-1 for values of k and C, as required in the following examples.

Solution. From Equation 2

$$U = \frac{1}{\frac{1}{2.0} + \frac{13}{5} + \frac{1}{2.0}} = \frac{1}{0.5 + 2.6 + 0.5}$$

$$U = \frac{1}{3.6} = 0.278$$

From Equation 1, $q = 2000 \times 0.278(100 - 80)$

$$q = 11{,}120 \text{ Btu per hr.}$$

Example 2. Same as example 1, using a 9-in. brick wall outside, a 4-in. brick wall inside and an air space of 1 in. between the walls.

Solution.

$$U = \frac{1}{\frac{1}{2.0} + \frac{4}{5} + \frac{1}{1.25} + \frac{9}{5} + \frac{1}{2.0}}$$

$$U = \frac{1}{0.5 + 0.8 + 0.8 + 1.8 + 0.5}$$

$$U = \frac{1}{4.4} = 0.227$$

$$q = 2000 \times 0.227(100 - 80)$$

$$q = 9080 \text{ Btu per hr.}$$

Example 3. (a) Find the heat transmission coefficient of a roof consisting of 2 in. by 4 in. rafters, ¾ yellow pine sheathing with asbestos shingles on top. (b) Same roof with aluminum foil fastened to bottom side of roof rafters and (c) with 3½ in. of rock wool filled in between the rafters substituted for the aluminum foil.

Solution.

(a)
$$U = \frac{1}{\frac{1}{2} + \frac{\frac{3}{4}}{0.8} + \frac{1}{6} + \frac{1}{2}} = 0.475$$

(b)
$$U = \frac{1}{\frac{1}{2} + \frac{1}{46} + \frac{\frac{3}{4}}{0.8} + \frac{1}{6} + \frac{1}{2}} = 0.234$$

(c)
$$U = \frac{1}{\frac{1}{2} + \frac{3.5}{0.27} + \frac{\frac{3}{4}}{0.8} + \frac{1}{6} + \frac{1}{2}} = 0.0665$$

Sun Effect and Radiation. This factor has been the most unknown to the air conditioning trade. The other factors had been studied thoroughly in heating and ventilating research but since the peak loads of heating came during the absence of sunlight, its effects were generally ignored. In cooling its effects are most marked during the period of greatest cooling demand.

Radiant heat may be transmitted through transparent and translucent materials either coming directly from the sun or may be reflected from surfaces near by. Light-colored smooth surfaces reflect large quantities of heat whereas dark and rough surfaces absorb heat.

H. M. Hendrickson has presented a table which summarizes the variations of heat gain from sunlight for different latitudes, and positions as given in Table 22-2.

TABLE 22-2. DIRECT SUNLIGHT GAIN ON GLASS *

(Btu per Sq. Ft. per Hr.)

Exposure	For Net Glass Area			For Sash Area (85% Glass)		
	50° L.	40° L.	30° L.	50° L.	40° L.	30° L.
East	165	165	165	140	140	140
Southeast	155	140	130	130	120	110
South	140	120	90	120	100	75
Southwest	160	145	135	135	125	115
West	175	175	175	150	150	150
Horizontal (skylight)	210	235	260	180	200	220

* H. M. Hendrickson, "How to Figure Air Conditioning," A.S.R.E.

The total quantity of outside air used as a basis for design load calculations shall be the infiltration or the air required for ventilation, whichever is the greater.

Shading the windows cuts down the heat gain from sunlight greatly. Shading to be most effective should be applied to the entire window but should permit freedom of air, circulation from beneath the awning or shading appliance. This will prevent an accumulation of very hot air next to the window.

The heat loss by convection is a function of temperature and wind motion. This can be controlled by controlling (1) the velocity of the air, (2) the temperature of the air, or (3) both.

Heat loss by evaporation is a function of temperature, relative humidity and wind motion.

To the human body, the effective temperature can be lowered at normal living conditions:

(1) By lowering the dry-bulb temperature and maintaining the wet-bulb stationary.

(2) By lowering the wet bulb and maintaining the dry bulb stationary.

(3) By lowering both the dry-bulb and wet-bulb temperatures.

At or above 44° F., the increase of the relative humidity or wet-bulb temperature increases the sensation of warmth. Below 44° F the increase of relative humidity increases the sensation of cold although the dry bulb may be held constant.

Relation of Refrigeration and the Central Station Power Load. A growing load of electric refrigeration for air conditioning is seriously affecting the installed capacity of many central stations. It is giving many station managers much concern.

In sections of the United States where the air-cooling season does not exceed six weeks, a heavy air conditioning load superimposed upon the existing plant load gives a peak for which a new investment in station equipment is hardly justified.

Many stations question the advisability of pressing the sales of air conditioning equipment unless provision is made to provide suitable holdover tanks so that the load can be shifted to the off-peak hours.

Outside shades are much more effective than inside shading. Inside shading permits much of the transmitted heat to be transferred to the room by convection currents around the shades.

Deep-well skylights and north windows may be omitted from sunlight gain computations but exposed skylights are serious offenders.

Venetian blinds and inside window shades will reduce the sunlight gain 35% to 40%, outside close-fitting metal blinds 50% to 70%, well-ventilated awnings 75%.

One of the low cost methods of reducing the sunlight heat gain is by painting the windows with white or buff cold water paints.

Heat from Lights, Motors and Equipment. For all used lights the wattage multiplied by 3.4 will give the heat load in Btu per hour.

For motors, 2545, the mechanical equivalent of heat of one horsepower hour, multiplied by a load factor of 75% and the installed horsepower will be usually sufficient.

For household refrigerator condensers, installed hot-water heaters, cooking equipment and steam tables and hot foods sufficient allowance should be made to assure coverage of the heat dissipated.

Body Heat. Body heat is a major factor in auditoriums, class rooms, stores, restaurants, work shops and hotel lobbies. The evaporation from the body increases the humidity while the heat released affects the temperature.

For convenience, Table 22-3 is arranged to give the heat emission from an adult body under different conditions.

TABLE 22-3. HEAT GIVEN OFF BY NORMAL ADULT UNDER DIFFERENT CONDITIONS

Condition	Heat Emitted, Btu per Hour
At rest	400
Light work	600
Moderate work	800
Heavy work	1200
Strenuous workout	2000

Air Changes. There is an opportunity for a serious error to be made in air-cooling computations if ample provision is not made for air changes.

Infiltration of air through porous plasters, doors, windows, and floors is much greater than commonly supposed.

The requisite amount of fresh air per occupant of the rooms per hour is a moot question also. The influence of a ventilating fan salesman in placing the air changes excessively high is in marked contrast to the counter influence of the salesman of inadequate self-contained portable cooling units who is determined to prove that his unit will "cool the room."

The habits of the public are an unknown factor in these air-change considerations. Many people feel that a room is close and stuffy "unless they can see an open window or ventilation opening."

The following values, Table 22-4, taken from the A.C.M.A. code is a fair guide to air changes.

TABLE 22-4. AIR REQUIREMENTS FOR DIFFERENT BUILDINGS

Application	Cubic Feet per Minute per Person	
	Preferred	Minimum
Apartments	15	10
Banking space	10	7½
Barber shops	10	7½
Department store	7½	5
Funeral parlor	10	5
Hospital rooms	15	10
Hotel rooms	15	10
Private offices	30	15
General offices	15	10
Restaurant	15	10
Small stores	15	12
Theaters	7½	5

For general applications each non-smoking person requires 7½ cu. ft. per min. maximum and 5 cu. ft. per min. minimum. Each person smoking requires 30 cu. ft. per min. maximum and 25 cu. ft. per min. minimum.

TABLE 22-5. PROPERTIES OF AIR

DRY AIR			SATURATED AIR, WATER VAPOR MIXTURE				
Temp. °F	Vol. in cu. ft. per lb.	Heat Content Btu per lb. dry air	Vol. in Cu. ft. per lb.	Btu per lb.	Grains Moisture per cu. ft.	Grains Moisture per lb. dry air	Latent heat Btu per lb. dry air
50	12.84	12.005	13.00	20.26	4.16	53.42	8.26
55	12.97	13.206	13.16	23.18	4.96	64.35	9.97
60	13.10	14.406	13.33	26.40	5.80	77.28	11.99
65	13.22	15.607	13.50	29.99	6.65	92.49	14.38
70	13.35	16.807	13.69	33.99	8.06	110.30	17.19
75	13.47	18.008	13.88	38.49	9.45	131.16	20.48
80	13.60	19.208	14.09	43.55	11.04	155.61	24.35
85	13.73	20.41	14.31	49.28	12.87	184.17	28.87
90	13.85	21.61	14.54	55.75	14.94	217.27	34.14
95	13.98	22.81	14.80	63.08	17.28	255.81	40.27
100	14.10	24.01	15.08	71.44	19.94	300.70	47.43
105	14.23	25.21	15.38	80.99	22.94	352.9	55.78
110	14.36	26.41	15.72	91.92	26.31	413.6	65.51
115	14.48	27.61	16.09	104.46	30.01	484.3	76.85
120	14.61	28.81	16.51	119.02	34.34	567.1	90.21

TABLE 22-6. PSYCHROMETRIC PROPERTIES OF AIR

SATURATED AIR			2° F. WET BULB DEPRESSION				4° F. DEPRESSION				6° F. DEPRESSION				8° F. DEPRESSION			
Dry Bulb ° F	Btu per lb at saturation	Grains per lb at saturation	Relative Humidity	Dew Point ° F	Grains per pound	Btu per pound	Relative Humidity	Dew Point ° F.	Grains per pound	Btu per pound	Relative Humidity	Dew Point ° F.	Grains per pound	Btu per pound	Relative Humidity	Dew Point ° F.	Grains per pound	Btu per pound
50	20.261	53 42	87	46.75	46 48	19 2	74	42.1	39.53	18.11	61	37.2	32.59	17.10	49	31.8	26.18	16.05
55	23.178	64.35	88	51.5	56 63	21.98	76	47.7	48.91	20.79	65	43 1	41 81	19 59	54	38.8	34 75	18.59
60	26.397	77.28	89	56.8	68.78	25 08	78	53.2	60.28	23 76	68	49.4	52.55	22 56	58	45 3	44.82	21.36
65	29.986	92.49	90	62.	83.24	28.55	80	58.8	73.99	27.11	70	55.2	64.74	25.67	61	51.5	56.42	24.40
70	33.994	110.30	90	67.	99.27	32 28	81	64.0	89.34	30.73	72	60.9	79 42	29.18	64	58.5	70.59	27.81
75	38.487	131.16	91	72.25	119.36	36.64	82	69.4	107.55	34.80	74	66.3	97.06	33.16	66	63 2	86.57	31.72
80	43.554	155.61	91	77.2	141.61	41 36	83	74 6	129.16	39 42	75	71.6	116.71	37.46	68	68.9	105.81	35.76
85	49.28	184.17	92	82.4	169.44	46 97	84	79.8	154.7	44.66	77	77.3	141.81	42.64	70	74.5	128.92	40.62
90	55.75	217.27	92	87.46	199.89	53.02	85	85.0	184 68	50.63	78	82.5	169.47	48.24	71	79 8	154.26	45.85
95	63.08	255.81	93	92.75	237.9	60.26	86	90.4	220.00	57.44	79	87.8	202 09	54.62	72	85.0	184.18	51.80
100	71.44	300.70	93	97.74	279.65	68.12	86	95.3	258 60	64.80	80	93.1	240.56	61.95	74	91.1	225.20	59.10
105	80.99	352.9	94	103.40	335.73	77.08	87	100.7	307.02	73.74	80	98.0	282 32	69 83	75	96.1	264.68	67.05
110	91.92	413.6	94	108.	388.78	88.59	87	105.7	359.83	83.4	81	103 3	335.02	79 47	76	102.3	314.34	76.20
115	104.46	484.3	95	112.7	450 08	100.62	88	111.0	426.18	95.24	82	108.8	397.13	90.63	77	107.7	372.91	86.78
120	119.02	567.1	95	118.33	538.75	114.51	89	116.5	505.72	109.10	83	114.1	470.69	103.68	78	113.4	442.34	99.17
SATURATED AIR			10° F. DEPRESSION				15° F. DEPRESSION				20° F. DEPRESSION				25° F. DEPRESSION			
50	20.261	53.42	38	25.6	20.30	15.14	10	0.	5.34	12.83								
55	23.178	64.35	43	33.1	27.67	17.49	19	15.0	12.23	15.10								
60	26.397	77.28	48	40.43	37.09	20.16	26	25.4	20.09	17.52	5	8.0	3.86	15.01				
65	29.986	92.49	52	47.16	48.09	23.08	31	34.0	28.67	20.06	13	14.0	12.02	17.48				
70	33.994	110.30	55	53.41	60.67	26.26	36	42.2	39.71	22.99	19	26.4	20.96	20.07	3	11.0	3.31	17.32
75	38.487	131.16	59	60.04	77.38	30.09	41	50.1	53.78	26.40	25	37.3	32.79	23.13	9	15.0	11.80	19.85
80	43.554	155.61	61	65.75	94.92	34.06	44	56.8	68.47	29.92	29	45.5	45.13	26.27	15	29.0	23.34	22.86
85	49.28	184.17	63	71.45	116.03	38.60	47	63.1	86.56	33.98	33	53.5	60.78	29.94	20	40.3	36.83	26.18
90	55.75	217.27	65	77.14	141.23	43.80	50	69.6	108.64	38.68	37	61.1	80.39	34.24	24	49.4	52.15	29.80
95	63.08	255.81	67	82.3	171.39	49.39	52	75.4	133.02	43.75	40	68.0	102 32	38.52	28	58.0	71.63	34.09
100	71.44	300.70	69	88.59	207.48	56.74	55	81.8	165.39	50.10	42	74.0	126.29	44.41	31	65.2	93.22	38.71
105	80.99	352.9	70	93.	247.03	64.26	56	87.1	197.62	56.45	44	79.9	155.28	49.75	33	71.6	116.46	43.62
110	91.92	413.6	71	99.25	293.66	72.92	57	92.4	235.75	63.75	46	85.9	190.26	56.55	36	78.6	148.9	49.99
115	104.46	484.3	72	104.6	348.70	82.94	59	98.3	285.74	72.95	48	92.1	232.46	64.50	39	85.8	188.88	57.58
120	119.02	567.1	73	110.	413.98	94.66	60	103.9	340.26	82.94	50	98.1	283.55	73.92	41	92.1	232.51	65.8

In heating mixtures of dry air and water vapor, the heat required to raise the air temperature is equal to the specific heat of the mixture times the temperature change.

But in cooling a saturated mixture of dry air and water vapor, sufficient cooling must be added to cool the dry air and to condense part of the contained water vapor.

For example to cool a pound of saturated air from 100° F. to saturated air at 85° F. would require

Btu in one pound saturated air at 100° F. = 71.44
Btu in one pound saturated air at 85° F. = 49.28

Btu that must be extracted per pound 22.16

Table 22–5 is given showing the properties of dry and saturated air. Table 22–6 is an extension of Table 22–5 and gives the heat value at different degrees of wet-bulb depression. These values can be used for all computation or the same values can be found on psychrometric charts available from manufacturers of air conditioning equipment.

Example. Three hundred pounds of outside air at a dry-bulb temperature of 90° F. and a wet bulb of 80° F. are mixed with 150 lbs. of saturated air at 60° F. What will be the moisture and the heat content of each pound of mixture?

Solution. From Table 22–6, 90° F. dry-bulb air with a 10° F. depression wet bulb (80° F.) the moisture content is 141.23 grains per lb.

300 × 141.23 = 42,369 grains.
The moisture in 60° F. saturated air is 77.28 grains per lb.
150 × 77.28 = 10,592 grains.
Total moisture in 450 lbs. new mixture = 52,961 grains.
Moisture in 1 lb. new mixture = $\frac{52{,}961}{450}$ = 117.7 grains.
Total heat in outside air at 90° F. dry bulb and 80° F. wet bulb = 43.8 × 300 = 13,140 Btu.
Total heat in saturated air at 60° F. = 26.397 × 150 = 3959.6 Btu.
Total heat in 450 lbs. new mixture = 17,099.6 Btu.
Heat in 1 lb. new mixture = 38 Btu.

Some Regulations Specified by the Air Conditioners Manufacturers Association

"The name 'Air Conditioner' or 'Air Conditioning' shall not be applied to any air treating combination which is not designed to embody the minimum complement of functions as defined below. If a system embodies less, it shall be called by a name which describes only the functions performed, and does not incorporate the words 'Air Conditioning' or 'Air Conditioner.' '

Definitions.

(1) *Application engineering standards* for air conditioning are those relating to conditions and factors which form the basis of design load estimating and specifications of performance. These are distinguished from standards of apparatus design, of installation practices and of safety.

(2) *The design load* is the capacity required of the apparatus to maintain specified conditions inside when specified extreme conditions of temperature and humidity obtain outside and when all sources of load are taken at the maximum that will occur coincidentally, during periods of outside extremes.

(3) *Design inside conditions* are the dry- and wet-bulb temperatures (or relative humidity) specified to be maintained inside at the time of occurrence of the design load.

(4) *Design outside conditions* are the dry- and wet-bulb temperatures (or relative humidity) specified for design load computation.

(5) *Comfort air conditioning* provides ventilation, air circulation, air cleaning and maintains temperature and humidity for the comfort of people.

(6) *An air conditioning system* provides ventilation, air circulation, air cleaning and equipment for maintaining temperature and humidity within prescribed limits.

(7) *An air conditioner* is a specific combination consisting of means for ventilation, air circulation, air cleaning and heat transfer with control means for maintaining temperature and humidity within prescribed limits.

(8) *A cooling (summer) air conditioner* is a specific air-treating combination consisting of means for ventilation, air circulation, air cleaning, cooling and dehumidifying with control means for maintaining room temperature and humidity within prescribed limits.

(9) *A heating (winter) air conditioner* is a specific air-treating combination consisting of means for ventilation, air circulation, air cleaning, heating and humidifying with control means for maintaining room temperature and humidity within prescribed limits.

Design Load Factors. The following shall be specified as a basis for the calculation of design loads.

(1) Design inside conditions.
(2) Design outside conditions.
(3) Number of occupants and other sources of substantial load from within doors.
(4) Cubic feet per minute per person assumed for ventilation.
(5) Time of day at which maximum load is estimated to occur.
(6) Class of activity assumed for occupants.

Calculations of design loads shall include the following sources of heat gain:

(1) Conduction through physical barriers, such as walls, doors windows, floors, ceilings, etc.
(2) Heat from sunshine.
    (a) Direct effect through glass areas exposed to the sun.
    (b) Additional conduction through opaque barriers, such as walls, roofs, etc., exposed to the sun.
(3) Heat and moisture introduced by incoming outdoor air.
(4) Heat and moisture liberated by occupants.
(5) Heat and moisture liberated by appliances, illumination, combustion, etc.

The basis of all these design load values shall conform with the data in the current issue of the ASHVE Guide except where these standards give other specific requirements.

The design outside conditions for cooling shall be the average for ten years of the highest dry- and wet-bulb temperatures remaining each year after excluding those higher temperatures which have occurred on only ten days of each year and for durations of less than 3 hrs.

The design inside temperature and humidity shall be not more than that shown in Table 22-7.

Note. It is recognized that in certain unusual localities, the outside design dew point is substantially less than the dew point of the tabulated inside design conditions. In such cases, the code committee will entertain the recommendations by local authorities of the inside design conditions for use in those localities.

Other Psychrometric Considerations. Under normal conditions, all of our room temperatures are taken with a dry-bulb thermometer, that is a thermometer with its glass mercury bulb exposed to the atmosphere.

A wet-bulb thermometer has its bulb covered with a piece of clean soft cloth which must be moistened with water before reading. The wet-bulb thermometer will give a lower temperature reading than the dry-bulb thermometer in proportion to the amount of evaporation from the surface of the wetted cloth on the wet-bulb thermometer.

TABLE 22-7. INSIDE DESIGN CONDITIONS FOR COMFORT COOLING

OUTSIDE DESIGN DRY BULB °F.	CLASS AA SPECIAL APPLICATION OCCUPANCY OVER 40 MIN.			CLASS A AVERAGE APPLICATION OCCUPANCY OVER 40 MIN.			CLASS B OCCUPANCY UNDER 40 MIN.		
	Dry Bulb °F	Wet Bulb °F	R.H.%	Dry Bulb °F	Wet Bulb °F	R.H.%	Dry Bulb °F	Wet Bulb °F	R.H.%
85	73	64	64	74	64	60	75	64	57
	74	62	53	75	62	50	76	63	48
	75	61	45	76	61	43	77	61	41
	76	59	38	77	59	35	78	59	32
90	75	66	65	77	67	62	78	68	60
	76	65	57	78	66	53	79	66	53
	77	63	48	79	65	48	80	65	45
	78	62	41	80	63	40	81	64	40
95	77	67	60	79	68	58	81	69	55
	78	66	54	80	67	51	82	68	49
	79	65	47	81	66	45	83	67	44
	80	64	42	82	65	40	84	66	38
100	78	69	65	80	69	58	82	70	57
	79	68	57	81	68	52	83	69	51
	80	66	50	82	66	44	84	68	45
	81	65	43	83	65	38	85	67	38
105	79	69	63	81	70	58	83	71	57
	80	68	57	82	68	51	84	70	50
	81	67	49	83	67	45	85	69	45
	82	66	43	84	66	39	86	68	40

When the wet-bulb and the dry-bulb thermometers read the same, the air is saturated. If a room of saturated air is cooled condensation will result.

The greater the difference of readings between the wet-bulb and the dry-bulb thermometers at any given dry-bulb temperature, the drier the air under test.

The dew point of air for a given moisture content is the temperature at which the air would reach a state of saturation when cooled.

Effective Temperatures. The human body reacts to temperatures between the dry-bulb and the wet-bulb thermometers usually designated the effective temperature.

The body loses heat by radiation, convection and evaporation.

The heat loss by radiation is proportional to the difference between the fourth powers of the hot and cool bodies.

Table 22–8. Latent Heats of Vaporization and Specific Volumes of Water Vapor

Temp., °F.	Vol. Sat. Vapor, cu. ft. per lb.	Latent Heat of Sat. Vapor	Temp., °F.	Vol. Sat. Vapor, cu. ft. per lb.	Latent Heat of Sat. Vapor
32	3306	1075.8	122	193.0	1114.5
34	3061	1076.7	124	184.0	1115.3
36	2837	1077.6	126	174.1	1116.2
38	2632	1078.4	128	165.5	1117.0
40	2444	1079.3	130	157.3	1117.9
42	2271	1080.2	132	149.7	1118.7
44	2112	1081.0	134	142.4	1119.5
46	1964	1081.9	136	135.6	1120.3
48	1829	1082.8	138	129.1	1121.2
50	1703	1083.7	140	123.0	1122.0
52	1588	1084.5	142	117.2	1122.8
54	1431	1085.4	144	111.8	1123.6
56	1382	1086.3	146	106.6	1124.5
58	1291	1087.1	148	101.7	1125.3
60	1207	1088.0	150	97.7	1126.1
62	1167	1088.9	152	92.68	1126.9
64	1056	1089.7	154	88.52	1127.7
66	988.4	1090.6	156	84.58	1128.6
68	925.9	1091.5	158	80.84	1129.4
70	867.9	1092.3	160	77.29	1130.2
72	813.9	1093.2	162	73.92	1131.0
74	763.8	1094.1	164	70.73	1131.8
76	717.1	1094.9	166	67.69	1132.6
78	673.6	1095.8	168	64.80	1133.4
80	633.1	1096.6	170	62.06	1134.2
82	595.3	1097.5	172	59.45	1135.0
84	560.2	1098.4	174	56.97	1135.8
86	527.3	1099.2	176	54.61	1136.6
88	496.7	1100.1	178	52.37	1137.4
90	468.0	1100.9	180	50.23	1138.1
92	441.3	1101.8	182	48.19	1138.9
94	416.2	1102.6	184	46.25	1139.7
96	392.8	1103.5	186	44.40	1140.5
98	370.9	1104.4	188	42.64	1141.3
100	350.4	1105.2	190	40.96	1142.0
102	331.1	1106.1	192	39.36	1142.8
104	313.1	1106.9	194	37.83	1143.6
106	296.2	1107.8	196	36.37	1144.4
108	280.3	1108.6	198	34.97	1145.1
110	265.4	1109.5	200	33.64	1145.9
112	251.4	1110.3	202	32.37	1146.6
114	238.2	1111.1	204	31.15	1147.4
116	225.8	1112.0	206	29.99	1148.2
118	214.2	1112.8	208	28.88	1148.9
120	203.3	1113.7	210	27.82	1149.7
			212	26.80	1150.4

ABSORPTION REFRIGERATION FOR AIR CONDITIONING

In the All-Year Gas Air Conditioning Unit of the Servel unit, refrigeration is produced by the absorption principle.

The system is charged with lithium bromide and water, the water acting as the refrigerant. The entire cycle operates under a vacuum.

In Figure 22-1 Dr. R. S. Taylor * describes the cycle as follows:

> . . . (*AH*) is the vapor lift pump and generator combined. Vapors from this pass up through (1) into the condenser (*B*). Condensed refrigerant goes to the evaporator (*E*) through the trap (*C*) which is sufficiently deep that it will always form a trap under all differences in pressure encountered in the operation of the unit. Thus the trap (*C*) replaces an expansion valve or float control.
>
> The refrigerant evaporates in the evaporator (*E*) producing refrigeration and the vapors pass down the channels on the two ends of the evaporator into the absorber (*F*). Absorbent weak in refrigerant passes from the generator through

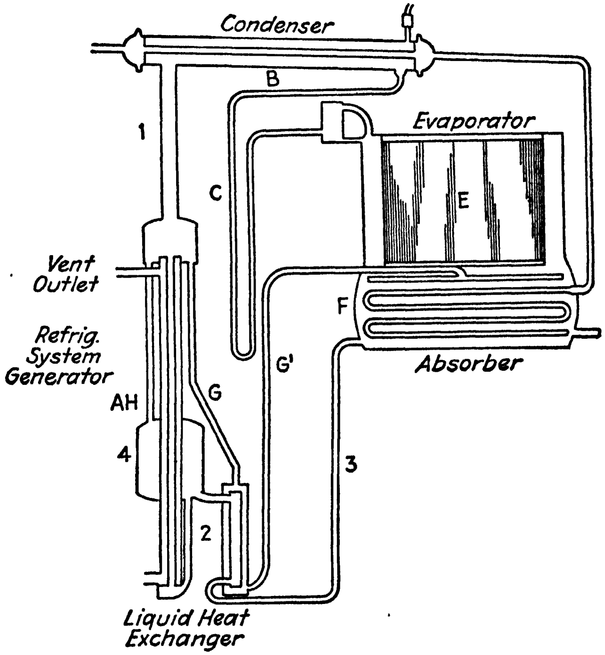

FIG. 22-1. Servel air conditioner unit.

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* *Refrigerating Engineering,* March, 1945, pp. 190-191.

the pipe (*G*), liquid heat exchanger (2) and pipe (*G'*). Here again (*G*) and (*G'*) form two legs of a trap the bottom of which also contains the liquid heat exchanger and the heights are such that a trap is always formed regardless of the pressure differences encountered between the absorber and generator in operation of the unit. Hence this trap replaces the weak liquid control valve in a standard absorption unit.

The absorption solution rich in refrigerant flows from the absorber through pipe (3) and liquid heat exchanger (2) into the pot or container (4). This serves as a feed for the vapor lift pump (*AH*) which raises the liquid to the higher pressure and level in the unit. Hence, the vapor lift replaces the mechanical pump or transfer device in other absorption units. The vapor lift and generator is heated by atmospheric steam entering at the bottom. The condenser and absorber are cooled with water as shown.

Either natural or manufactured gas is used as a fuel for winter operation and as a source of energy to operate the absorption unit in the summer. During the winter season steam is delivered to a unit heater for distribution. In the summer the steam is delivered to the absorption refrigeration unit contained in the same packaged system. An automatic temperature control delivers heat or cooled air as the weather conditions might require. Units of 3 and 5 tons refrigeration capacity are available.

Evaporative Cooling. In the dry climates, considerable progress has been made in evaporative cooling. Air is passed through the water spray in which the water is continuously recirculated. When the dry air enters the spray it evaporates part of the water and gives up some of its sensible heat. This lowers the dry bulb sometimes to the point of saturation. The reduction of the dry bulb is a direct function of the wet-bulb temperature of the entering air. Thus, this system is more adaptable to climates of low humidity.

If it is desirable to hold the humidity down as low as possible, part of the incoming air may be bypassed, thus providing a delivery of air to the room below saturation.

Air Cooling with Well Water. Cold well water, when available at temperatures below 65° F., is usually very economical as a cooling agent. If used in closed pipe coils it may dehumidify as well as cool the air. If used as a spray it may increase the wet-bulb temperature but lower the dry-bulb sufficiently to give a decreased effective temperature.

Night Air Cooling. In areas where the temperature drops appreciably at night, night air cooling may be very effective. Attic circulating fans increase the air circulation, quickly replacing the house air at night, and give the rooms a cooler start into a hot day. If such homes are well insulated it is common for them to maintain temperatures 6 to 8° F. below the outside when closed up against air changes during the hotter hours of the day. Opening the windows on the first floor and circulating air through these rooms during the early evening, and through the second floor rooms during the rest of the night provides maximum comfort for the occupants.

THE HEAT PUMP OR REVERSED CYCLE REFRIGERATION

In 1852 Lord Kelvin proposed to the Glasgow Philosophical Society the "Heating and Cooling of Buildings by Means of Currents of Air." His discourse can be found in Volume 3, December 1852, of the publication of that Society. It was three quarters of a century before Lord Kelvin's outlined procedure became more than a scientific laboratory experiment.

As indicated in Figure 22–2 on the enthalpy-pressure diagram the cooling that must be supplied the condenser totals the combined heat supplied to the refrigerant in the cooler and the compressor.

The *coefficient of performance* represents the ratio of the amount of heat supplied by the cooler to that supplied by the compressor. Since this ratio is always much higher than *one* it follows that the amount of heat supplied by the compressor is much less than one half of the heat made available for heating the condensing water on the other side of the diagram.

If this condensing water, after being raised in temperature by the condensing refrigerant, is utilized for hot-water heating, there will be made applicable a system that can furnish cooling capacity in the evaporator and heating capacity from the condensing water. Since the relation of the amount of heat furnished the compressor motor is only a fraction of the total heat made available by the condenser, this system lends itself to electric heating. The electric heat furnished the motor is supplemented by the heat of the evaporator to provide a total available condenser heat considerably greater than the kilowatt-hour heat input to the motor.

Unfortunately, in most locations the available cooling water is hot in summer and cold in winter. For effective use of the condensing water for heating, the temperature of the water coming from the condenser should be high enough to furnish considerable heating capacity without requiring too much radiator surface. Thus, for practical applications, the winter cooling water should be warm relative to the outdoor temperature, and the summer cooling water should be cool relative to the outdoor temperature.

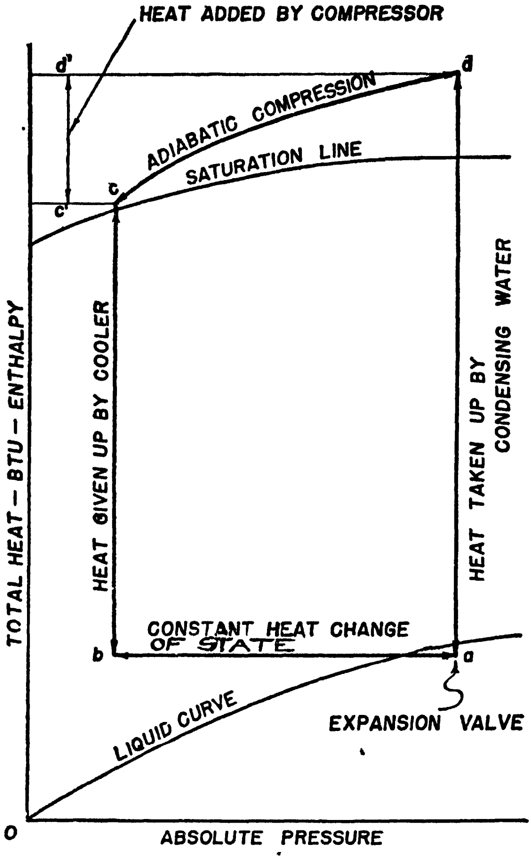

FIG. 22-2. Typical refrigerant cycle as a heat pump. 1. Liquid refrigerant of receiver passes through expansion valve to cooler. No heat change from *a* to *b*. 2. Products in cooler give up heat to boil and vaporize refrigerant. This is the *refrigeration effect b–c*. 3. Slightly superheated vapor refrigerant enters compressor at *c*. Heat of compression increases temperature and heat of refrigerant from *c* to *d*. The refrigerating effect *b–c* divided by the heat added by compressor *c′–d′* equals the coefficient of performance as a refrigerator. 4. Superheated refrigerant at temperature *d* enters the condenser at *d*. The cooling water of condenser takes up the heat of condensing refrigerant equal to *d–a*. The heat taken up by the condenser water *a–d* divided by heat of compression *c′–d′* equals the coefficient of performance as a heating system.

Usually the most satisfactory water supply for such a system is a deep well. By using a well supply the heat reserve within the ground is utilized in winter, and the moderate relative coolness of the ground water is most acceptable for summer.

Where a permanent spring or well supply of water is available reversed cycle heating and cooling can be considered practical if the electric rates are sufficiently low for domestic heating and the mean temperature of the heating months are not too low. In most climates the winter heating load is so much greater than the summer cooling requirements that no economical balance can be worked out even with satisfactory water temperatures and low electric rates.

At the present state of the art there is little justification for utilizing the heat pump or reverse cycle principle in the United States north of the 35th parallel except on the coast. In England, where the climate is tempered by the Gulf Stream, Haldane and others have used the principle successfully at much more northerly latitudes.

Coefficient of Performance in Reversed Cycle Refrigeration. The pressure-enthalpy diagram of a typical refrigeration cycle indicates clearly the relationship of terms involved in the coefficient of performance. The cycle as shown in the pressure-enthalpy diagram on page 634 occurs as follows: the liquid refrigerant passes through the expansion valve into the evaporator coils of lower pressure. In the evaporator the refrigerant absorbs heat at constant pressure. When vaporized the refrigerant is drawn into the compressor and compressed approximately along the adiabatic curved line and is discharged into the condenser at its maximum pressure and temperature. In the condenser the refrigerant gives up heat to the cooling water and is liquefied.

Since the definition of the coefficient of performance is the ratio of useful work to the work done on the refrigerant by the compressor it follows that two coefficients of performance can be considered in the reversed cycle application. First, when the compressor is considered as a heat pump the

$$\text{Coefficient of performance} = \frac{\text{Heat diffused by condenser}}{\text{Work done by the compressor}}$$

When the compressor is considered as a refrigerant pump the

$$\text{Coefficient of performance} = \frac{\text{Heat absorbed by evaporator}}{\text{Work done by compressor}}$$

Since the heat diffused by the condenser is equal to the heat absorbed by the evaporator plus the work done by the compressor it follows that the coefficient of performance of the system considered as a heat pump will always be greater for the same system than the coefficient of performance of the system considered as a refrigerator. A system that has a theoretical coefficient of performance as a refrigerator of 4.5 will have a coefficient of performance as a heat pump of 5.5.

Advantages and Disadvantages of the Heat Pump or Reversed Cycle Refrigeration System. The principal disadvantages found today in the adoption of the heat pump principle are (1) the high cost of the installation and (2) the need of a suitable supply of warm condensing water when operating as a heating machine, (3) the large heating surface required on account of the low temperatures of the heating liquid.

In so many localities of the United States energy in the form of heat can be purchased at a relatively low price and in such localities the heat pump has severe competition. In many other areas where the fuel costs are sufficiently high to justify the heat pump process of supplying heat energy, the available cooling water is too cold during the heating season to make the heat pump process economical.

The principal advantages of the heat pump are (1) it eliminates combustion gases and the resultant smoke nuisance, (2) it makes possible both air cooling and air heating from one piece of equipment and, (3) it boosts the heat return for each kilowatt hour consumed by an amount equal to the heat pick-up in the refrigerator. This is usually 3.5 to 4.5 times the heat of electrical energy consumed.

In Figure 22–2 the heat taken away by the condensing water is available for heating. Its availability is dependent upon the temperature of the water coming off of the condensing coils. If the temperature of this water is 90° F. and the room to be heated is 70° F., hot-water radiators, sufficient to heat the room with a 20° F. differential or 90 – 70, are necessary.

If the condensing water is coming from a warm source such as a well, it might be possible to have the condensing water coming from the coils at 125° F. This would give a differential of 125 – 70 or 55° F. and the hot-water radiator surface could be reduced to 36⅓% of what it was when using 90° F. water for heating.

TABLE 22-9. APPROXIMATE WELL-WATER TEMPERATURES IN U.S.A.

State	City	Mean Well-water Temperature, °F.
Alabama	Birmingham	65
Arizona	Tucson	67
Arkansas	Little Rock	65
California	Sacramento	62
Colorado	Denver	48
Connecticut	Hartford	51
District of Columbia	Washington	57
Delaware	Wilmington	56
Florida	Jacksonville	70
Georgia	Atlanta	64
Idaho	Boise	47
Illinois	Springfield	55
Indiana	Indianapolis	54
Iowa	Des Moines	50
Kansas	Topeka	55
Kentucky	Lexington	57
Louisiana	Baton Rouge	69
Maine	Augusta	45
Maryland	Annapolis	57
Massachusetts	Springfield	49
Michigan	Lansing	47
Minnesota	St. Paul	45
Missouri	Jefferson City	57
Nebraska	Lincoln	53
Nevada	Reno	52
North Dakota	Bismarck	43
New Hampshire	Manchester	45
New Jersey	Trenton	55
New York	Albany	46
North Carolina	Raleigh	63
New Mexico	Albuquerque	57
Ohio	Columbus	55
Oklahoma	Oklahoma City	64
Oregon	Portland	52
Pennsylvania	Harrisburg	52
Rhode Island	Providence	52
South Carolina	Columbia	65
South Dakota	Pierre	47
Tennessee	Nashville	59
Texas	Austin	70
Utah	Salt Lake City	52
Vermont	Burlington	45
Virginia	Richmond	59
West Virginia	Charleston	52
Washington	Seattle	52
Wisconsin	Madison	47

TABLE 22-10. DEGREE DAYS FOR CAPITAL CITIES (C) AND ONE OTHER CITY OF EACH STATE

City and State	Degree Days
Alabama	
Birmingham	2,485
Montgomery (C)	1,904
Arizona	
Phoenix (C)	1,425
Yuma	918
Arkansas	
Fort Smith	3,223
Little Rock (C)	2,905
California	
Sacramento (C)	2,653
Los Angeles	1,504
Colorado	
Denver (C)	5,870
Delta	6,003
Connecticut	
Hartford (C)	6,030
New Haven	5,805
Delaware	
Dover (C)	4,591
Wilmington	4,789
District of Columbia	
Washington (C)	4,614
Florida	
Miami	0
Tallahassee (C)	1,230
Georgia	
Atlanta (C)	2,940
Savannah	1,550
Illinois	
Chicago	6,288
Springfield (C)	5,423
Idaho	
Boise (C)	5,402
Sand Point	7,320
Indiana	
Evansville	4,204
Indianapolis (C)	5,395
Iowa	
Des Moines (C)	6,389
Sioux City	6,895
Kansas	
Topeka (C)	5,203
Wichita	4,675
Kentucky	
Frankfort (C)	4,220
Lexington	4,718
Louisiana	
Baton Rouge (C)	1,350
New Orleans	1,048
Maine	
Augusta (C)	8,320
Orono	7,934
Maryland	
Annapolis (C)	4,483
Cumberland	5,796
Massachusetts	
Boston (C)	6,025
Williamstown	7,235
Michigan	
Detroit	6,540
Lansing (C)	7,094
Minnesota	
St. Paul (C)	7,937
International Falls	10,121
Montana	
Helena (C)	7,898
Havre	8,630
Mississippi	
Jackson (C)	1,967
Corinth	3,323
Missouri	
Jefferson City (C)	4,879
St. Louis	4,597
Nebraska	
Lincoln (C)	6,102
Fort Robinson	7,097
Nevada	
Carson City (C)	5,750
Winnemucca	6,351
New Hampshire	
Concord (C)	7,373
Hanover	8,025
New Jersey	
Newark	5,393
Trenton (C)	4,974
New Mexico	
Carlsbad	2,589
Santa Fe (C)	6,123
New York	
Albany (C)	6,589
Buffalo	6,923
North Carolina	
Asheville	4,252
Raleigh (C)	3,254

TABLE 22-10. DEGREE DAYS FOR CAPITAL CITIES (C) AND ONE OTHER CITY OF EACH STATE (*Continued*)

City and State	Degree Days	City and State	Degree Days
North Dakota		Texas	
Bismarck (C)	9,172	Austin (C)	1,585
Grafton	10,277	Amarillo	4,370
Ohio		Utah	
Columbus (C)	5,478	Logan	6,768
Cleveland	6,164	Salt Lake City (C)	5,595
Oklahoma		Vermont	
Oklahoma City (C)	3,672	Burlington	7,724
Tulsa	3,579	Montpelier (C)	8,715
Oregon		Virginia	
Salem (C)	4,608	Richmond (C)	3,837
Portland	4,449	Roanoke	4,128
Pennsylvania		Washington	
Harrisburg (C)	5,395	Olympia (C)	5,266
Pittsburgh	5,315	Spokane	6,325
Rhode Island		West Virginia	
Newport	5,690	Charleston (C)	3,799
Providence (C)	6,015	Wheeling	5,238
South Carolina		Wisconsin	
Columbia (C)	2,434	Madison (C)	7,457
Greenville	3,385	Superior	9,755
South Dakota		Wyoming	
Pierre (C)	7,633	Cheyenne (C)	7,523
Aberdeen	8,229	Yellowstone Park	9,559
Tennessee			
Nashville (C)	3,557		
Memphis	2,970		

It must be recognized, however, that increasing the condensing water temperature coming from the condensers also raises the head pressures of the compression system which in turn increases the power requirements of the system.

A table of degree days of heating is presented herewith. Also a table which shows the temperature of well water in different sections of the United States. In general the temperature of the ground water is approximately equal to the mean annual temperature of the area. From these tables it is evident that the field of application of the heat pump is in the warmer climate of the United States.

Degree Days. The degree day is based on an outside temperature of 65° F. By actual record fuel is used in heating buildings in proportion to the mean temperature of each day below an outside temperature closely approximating 65° F. Consequently, 65° F. has been accepted as the base point. For example, if the temperature readings for an area average for the second of December 51° F. then the degree days for that particular day would be 14 degree days.

Values are available of the degree days for each month of each year for most areas of the United States for the past twenty years. The degree days for a typical year for the capital city and one other of each state are given in Table 22–9.

Railroad Passenger Car Air Conditioning. For railroad passenger car air conditioning four principal systems are used.

(1) The steam Ejector system. The extra boiler capacity which is provided for steam heating in the wintertime is utilized for summer train cooling.

The condenser is cooled by an evaporative principle wet-air blast. The condenser temperature is proportional to the wet-bulb temperature of the atmosphere.

The refrigerator unit is installed either between the car roof and ceiling or under the car. Most present-day installations are above the ceiling.

The automatic control regulates the evaporative fan speed and amount of water spray.

(2) Direct mechanical compression system. The compressor is driven directly from the car axle with the speed controlled by an automatic electric induction clutch.

(3) The electric driven compressor. In this system a d-c motor drives the compressor, an axle driven generator furnishing the current under the higher speeds of the train and a storage battery furnishing the current at low speed.

(4) Ice system. In the ice system water is cooled by spraying over the ice in the bunkers beneath the car then circulated through the air cooling coils.

The report of the Air Conditioning of Railroad Passenger Cars of the Association of American Railroads for 1937 showed comparative costs.

(1) For the three months cooling season the total cost per 1000 car miles including fixed charges, operating and maintenance costs with an average train speed of 50 mph and a total mileage of 150,000 car miles per year was:

Ice-activated Systems	$ 9.48
Electro-mechanical Compression Systems	12.63
Steam Ejector System	14.25
Direct Mechanical Compression System	14.49

(2) For an eight months cooling season the total cost per 1000 car miles including fixed charges, operating and maintenance costs with an average train speed of 50 mph and a total mileage of 150,000 car miles per year was:

Electro-mechanical System	$12.99
Ice-activated System	14.22
Steam Ejector System	14.51
Direct Mechanical Compression System	14.78

Effectiveness of Car Insulation. The refrigeration required to equal the heat transferred to the inside with a 20° F. temperature difference.

Railroad authorities recommended in their report

(1) 1.3 tons of refrigeration for the best car.

(2) 3.1 tons of refrigeration for the poorest.

Sun Effect and Air Motion. Three tons of refrigeration were required for the average passenger car to provide the (1) heat load with a 20° F. temperature difference, (2) the sun effect and (3) air change effect at 50 mph.

The consensus supported by practical experience indicates that the probable desirable limits for conditions in air-conditioned cars should be:

(1) Inside temperature from 72° F. to 76° F., with a minimum of 70° F., and a maximum of 80° F.

(2) Inside relative humidity from 40 to 60%, with a minimum of 30%, and a maximum of 70%.

(3) Inside temperature distribution.—A difference in average temperatures not in excess of 2° between any two positions in the cars; and the average temperature at the ankle level not more than one degree below that at the head level of a person seated.

(4) Inside average air movement from 25 to 75 ft. per min.

(5) Volume of fresh air delivered through the cooling system per passenger.

(a) For normal conditions a minimum of 10 cu. ft. per min.

(b) Where smoking is permitted, 12 to 15 cu. ft. per min.

Refrigeration requirements for passenger cars and coaches vary considerably in different climatic conditions.

For Pullmans in northern locations 5 tons of refrigeration is ample. For southern areas it will require 7 tons.

In northern climates 6 tons of refrigeration is sufficient for the diner. In southern areas it will require 8 tons.

For day coaches an average of 7 tons is sufficient in northern climates. For southern locations it requires from 8 to 8½ tons.

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SECTION XXIII

MARINE REFRIGERATION

General. The basic principles of refrigeration apply with equal rigor to either marine or land installations. However, there are many details of construction and operation not of great importance in the stationary plant, that become matters of vital necessity in the ship's refrigeration system. It may be stated that safety and dependability are the most important characteristics of the marine installation and that neglect of these essentials may lead to disaster.

A ship's hold is cramped and usually poorly ventilated; thus, any leakage of toxic refrigerant fluid cannot be permitted. Because of this danger, the dense-air machine held the field unchallenged for a considerable period, in spite of its poor efficiency. Later, the vapor compression system using nontoxic carbon dioxide was adopted to secure increased efficiency. In some cases, the still more efficient ammonia compression system has been employed to chill brine, which is piped to the refrigerator space. This permits all pipes carrying ammonia to be located in a compact space which is constantly under the supervision of the engineer so that leaks may be detected and repaired at once. Leakage of brine is a nuisance, but repairs to the faulty piping can be accomplished in the cramped spaces and pipe tunnels where it might be impossible to make repairs in the presence of escaping ammonia. The fact that ammonia is inflammable and forms explosive mixtures with air has further militated against its use for marine refrigerating systems.

The chloro-fluoro-substituted hydrocarbons, which are marketed under the generic trade name "Freon," have been shown to be among the relatively safe refrigerants and as a consequence have been widely employed for marine service. Systems using these refrigerants have efficiencies comparable with the ammonia cycle and much greater than the carbon dioxide or dense-air systems. The relative freedom from fire hazard and toxicity allows the primary refrigerant to be piped directly to the refrigerated space, since in case of leaks the only damage is the loss of refrigerant.

The marine installation does not have access to any replacement or repair facilities other than those available on the ship itself; for this reason reliability is of great importance. Duplicate compressors may be installed of such size that either may carry the entire load or the load may be divided between two smaller units so that failure of one does not involve complete loss of refrigeration. The constant vibration of the main propelling engines and flexing of the ship's structure in storms produce stresses in the piping which are not encountered in land installations. Pipe joints are likely to leak under these conditions and the resulting loss of refrigerant may exhaust the available reserve supply on board. Welded or hard-soldered pipe joints have greatly reduced the frequency of leaks where it is possible to use this method, but many connections must be made by means of threaded fittings and here the possibility of leakage is always present.

A complete stock of machine parts which are most likely to wear badly or to fail in service must be constantly maintained and a supply of pipe, valves, fittings and spare condenser tubes should be always on hand.

Marine refrigeration insulation is subject to contact with bilge water and air of high humidity; hence, it is necessary to select material having a high degree of resistance to moisture and to install it in a manner which will minimize the effect of this deteriorating agent. The previously mentioned vibration of the ship's structure will cause settling of loose fill insulation and will crack rigid insulating boards. It is desirable to use a board insulation which has sufficient resilience to yield to the flexing of the hull structure without acquiring a permanent deformation. The use of easily combustible material for marine insulation may contribute to disaster and is forbidden generally by shipping codes.

The fundamental refrigerant cycles, the heat transfer laws and the principles of refrigeration as they apply to shore installations are also applicable to refrigeration on ships.

Space limitations within the ship, vessel vibration, roll and pitch, and atmospheric and temperature changes from port to port all involve some special considerations in adapting refrigeration facilities to the marine cooling load. In marine practice, the four most commonly used refrigerants are atmospheric air, anhydrous ammonia, carbon dioxide and Freon.

Atmospheric Air Machines. Atmospheric air was extensively used for the refrigeration of ships throughout the early history of marine transportation of perishable foods. This type of equipment, known as either the dry air system or the dense air machine system, is still very popular in Great Britain and Europe. Today it is used especially on small cargo vessels that must move from port to port in isolated regions where ammonia, carbon dioxide or Freon would not be available. Since the air supply is unlimited, the dense air machine offers an ideal answer for the shipment of perishable goods between ports where refrigerant services are nonexistent.

As a refrigerant, air does not have a high economy. Its principal desirable characteristics for marine operation are: (1) absolute safety to human life, (2) its leakage has no bad effect upon the refrigerated load or the personnel, and (3) there is an unlimited supply of the refrigerant, air.

The cold-air compressor requires a different operating routine from other types of compression machines. The operator must give regular attention to removing the ice from the expander valves and to cleaning the snow from the trunks and snow boxes.

Carbon Dioxide Marine Systems. Carbon dioxide compression was introduced into marine practice soon after the development of the dense-air machine. It had certain characteristics that were equal to dry air for marine duty and its thermodynamic properties were better than those of air.

Carbon dioxide is very safe on ships since it is noninflammable and nontoxic, but it does have the disadvantage that it has a very low critical temperature of 87.8° F. With this low critical temperature the condensing water available in the tropical regions is usually above the critical point of the carbon dioxide; thus, the machine must work as a dry gas unit in such areas.

The compressor is the principal part of the carbon dioxide system to require attention. Since it must operate at pressures usually in excess of 1000 lbs. per sq. in., great care must be taken to keep the valves of the compressor in good condition to prevent leakage and consequent lowering of the capacity of the machine. Likewise, the piston packing must be carefully selected, installed and adjusted whether such packing is oil-treated molded leather or specially designed metallic material. Furthermore, unusual care must be taken to install the machine on a firm foundation since the compression stroke of the machine involves total crank pin pressures of several tons. The carbon dioxide condenser for marine installations is generally the double-pipe type with the sea water circulating through the inner pipe and the refrigerant in the outer pipe. This type of condenser is well adapted to the space limitations and the installation conditions of ships.

If the condenser pressure indicates a falling off while operating at normal load, speed and cooling water temperature, then an examination should be made of the amount of carbon dioxide in the receiver and system. The carbon dioxide system will operate much more economically when it has a full charge of refrigerant. On American-owned ships carbon dioxide refrigeration is on the decline and Freon 12 is rapidly taking its place.

Ammonia Marine Refrigeration. Ammonia has been used with much discretion on board ship. By virtue of its high toxic effects, great care must be used in the operation as well as in the installation.

Although ammonia adapts itself to operating at high thermodynamic efficiencies its objectionable toxic characteristics have made its use very limited in marine installations. All installations of ammonia should be made in sections of the boat isolated from the main engine and propelling machinery rooms.

Boats that are equipped with ammonia compressors usually limit the refrigerant lines to short runs to the brine coolers; then the secondary brine refrigerant lines are carried to the areas to be cooled. Most nations prohibit ammonia refrigeration on ships carrying passengers. On cargo ships it still finds some use but is installed in watertight compartments apart from the refrigerated storage.

Freon Marine Refrigeration. The advent of the Freons as refrigerants has brought to the marine refrigeration industry a class of refrigerants very suitable for installation on ships. All of the commercial Freons are relatively nontoxic and noninflammable and very suitable to ship refrigeration. They have thermodynamic properties competitive with those of ammonia.

This class of refrigerants requires very good construction of piping and system if leaks are to be eliminated, since the very nature of the refrigerants is such that a well-sealed system is required to retain it. To meet this situation, relatively short primary refrigerant lines are designed to service the brine coolers and cold diffusers. Since the longer lines carry only brine to the storage rooms, any leakage on the longer line can be readily detected and the refrigerant easily replaced. Freon leaks can go unnoticed for many hours without detection, and at a heavy cost of refrigerant loss.

Freon 12 is most generally used on commercial cargo and passenger vessels, although some installations of Freon 11 with centrifugal compressors have been made.

Some United States manufacturers are featuring completely self-contained units for marine installations. These units have been carefully designed to conserve space, yet are accessible for repair and inspection.

Refrigeration of Perishables on Ships. The refrigeration on board ship may be utilized (1) on passenger boats for the crew and passengers, (2) on naval vessels primarily for the men in the armed services that are assigned to the ship, and (3) on refrigerated cargo vessels for the perishable cargo and the essential crew.

For the smaller craft, such as pleasure and small commercial boats, refrigeration is usually available for the necessary crew and passengers, but such refrigeration is generally an adaptation of some of the condensing units used commercially for shore service.

The refrigeration of cargo ships dates back to the shipping of frozen meat to England from Texas and Australia in 1874 and 1875. The same principles of cold storage for cargo shipping are required as prevails for cold-storage operation in land installations. A uniform low temperature is a requisite of cold-storage operation whether on land or sea, but the period of storage on vessels is usually short, thus permitting more latitude in holding temperatures and humidities.

Great care should be taken in inspecting the foodstuffs to be taken aboard. Only sound frozen foods should be taken for transport in the freezers and equally prime foods should be arranged so that free circulation is obtainable in the storage compartments. The most satisfactory storage rooms are refrigerated by brine circulation to the storage room. Some of the older installations on board ship use a plenum chamber system by which the air is cooled and circulated by fans to the storage rooms. Some of the newer installations have utilized Freon 12 as a primary refrigerant and copper tube, cold-diffuser coils to supply the required refrigeration.

Brine circulating systems are recommended for large refrigeration installations especially where the compartments to be cooled are widely distributed and a central refrigeration plant is installed. The brine circulation system should be designed for liquid velocities of 150 to 200 ft. per min. and the temperatures of the circulated brine entering the room coils should be maintained from 10° to 12°

below the compartment temperature. The coils should be designed to give an in-and-out difference of temperature of the brine of not more than 5° F.

In many of the recent large cargo ships where unit direct-expansion refrigeration has been approved and installed, diffusers for unit coolers are serviced by a Freon 12 unit, each Freon unit functioning for one or two compartments. This unit system as applied to ships utilizes short refrigerant lines, thus eliminating much of the danger of leakage caused by ship vibration.

Marine Storage Temperatures in Great Britain and the United States. Storage practice on both shore and sea installations in the United States has dictated much lower refrigeration temperatures than are common in Great Britain. There is an increasing trend for the temperatures used for shore refrigeration to be more generally accepted for marine storage.

TABLE 23-1. TEMPERATURES RECOMMENDED FOR SHIP REFRIGERATION OF CARGO LOADS

−10° F. compartments for:
- Butter
- Frozen milk
- Ice cream

10° F. compartments for:
- Beef (frozen)
- Fish (glazed)
- Eggs (canned)
- Mutton
- Pork
- Poultry
- Shrimp

32–33° F. compartments for:
- Eggs (case)
- Fish (smoked)
- Grapes
- Pears
- Strawberries

35–36° F. compartments for:
- Cheese
- Apricots
- Apples
- Asparagus
- Cherries
- Milk
- Nuts
- Peaches
- Plums
- Melons
- Oysters
- Potatoes

40° F. compartments for:
- Citrus fruit
- Pineapples
- Tomatoes

55° F. compartments for:
- Bananas

70° F. compartments for:
- Sweet potatoes

Although the average period of storage is less on board ship than in commercial storage houses, there are always certain items that remain in ship storage for long periods. To assure the same maintenance in quality for marine-stored products as is acceptable in land installations, temperatures equaling or approaching those common to commercial storage are recommended. In all cargoes carrying unfrozen products ample provision should be made to adequately ventilate the storage rooms. In the fruit and vegetable compartments as many as three changes of outside air are supplied to the compartment. In the areas where low outside temperatures are encountered ample facilities must be provided to heat the air to be circulated and thus prevent the freezing or chilling of the contents of the compartment. Serious discoloration or other forms of decomposition will result if the ventilation is not adequate for those fruits and vegetables that are still living organisms and are giving off carbon dioxide and consuming oxygen.

Insulation of Refrigerated Ships. The insulation materials employed most commonly on boats are (1) molded cork, (2) granulated cork, (3) molded, waterproofed mineral wool, (4) loose-fill mineral wool and (5) fiber glass.

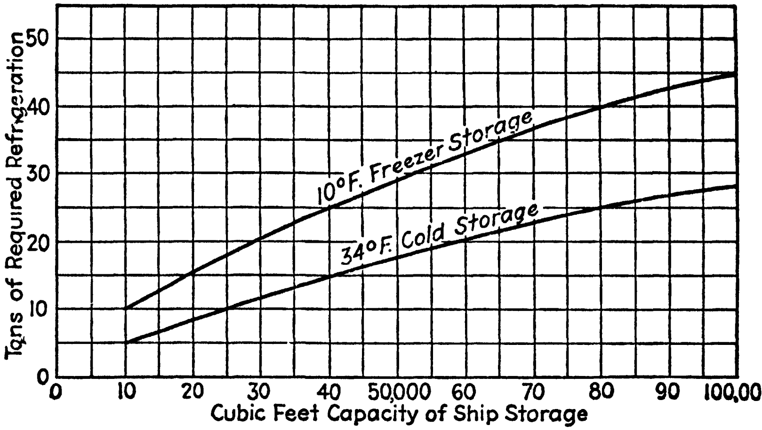

FIG. 23–1. Refrigeration demand—ship cold storage.

When loose-fill insulation is used on board ship it should be packed very tightly; otherwise, the vibration and rocking of the boat will shake the insulation down, creating empty spaces above the insulation.

The insulation requirements of refrigerator ships are not unlike those for land operation except that the space requirements make necessary the use of many areas where steel structural members cut across the space to be insulated. A large amount of loose-fill cork or fiber glass is often necessary to fill in such spaces around the steel sections. Again, because of the necessary inspection by the insurance company underwriting the cargoes and the authorized inspections of government agents, ready access to the insulated sections is often required. This calls for a judicious spacing of inspection panels in the refrigerated walls.

Because of the high humidities likely to prevail in vessels carrying foodstuffs in tropical climates, the moisture proofing of the insulation is very essential if water is to be kept out of the walls. Where moisture-sealed insulation can be used, it is recommended.

The inspection panels not only permit the checking of the structural members of the ship, but they are a very convenient aid in the detection of moisture in the insulation.

TABLE 23–2. ESTIMATED REFRIGERATION FOR COLD COMPARTMENTS OF SHIPS

Space Refrigerated, cu. ft.	Tons of Refrigeration Required, 10°F. Compartment	Tons of Refrigeration Required, 34° F. Compartment
10,000	10	5
20,000	15	8
40,000	25	15
60,000	33	20
80,000	40	25
100,000	45	28

Note: The refrigeration tonnage is much higher for ship refrigeration than for the same space on typical shore installations. Ship storage must be designed to operate in the world's hottest climates; it is subject to more opening and closing of entranceways than on land; and the insulation is subjected to much more severe vibration and shock than are ever experienced in shore installations.

TABLE 23-3. SHIPPING SPACE IN COLD STORAGE

Food Product	Cubic Feet of Needed Shipping Space per Ton, tons of 2240 lbs.
Almonds, bags	80
Apples, boxes	90
Bacon, cases	65
Beef, frozen	93
Beef, quarters	125
Bread, cases	155
Butter, tubs	70
Cheese, tubs	70
Coffee, bags	61
Dates, boxes	43
Fish, boxes	95
Fish, frozen	60
Flour, bags	47
Flour, barrels	60
Ham, barrels	70
Ice	39
Lard	70
Lemons	85
Margarine, tubs	69
Melons	80
Mutton	110
Oatmeal, bulk	61
Onions, boxes	77
Oranges, crates	90
Peas, bags	50
Potatoes, bagged	55
Prunes, casks	52
Rice, bags	48

MARINE UNITS AND THEIR EQUIVALENTS

Marine Shipping Units

16 ounces = 1 pound.
28 pounds = 1 quarter.
112 pounds (4 quarters) = 1 hundredweight.
1 register ton = 100 cubic feet.
1 United States shipping ton = 40 cubic feet.
1 United States shipping ton = 32.14 United States bushels.
1 United States shipping ton = 31.16 Imperial bushels.
1 English shipping ton = 42 cubic feet.
1 English shipping ton = 32.72 Imperial bushels.
1 English shipping ton = 33.75 United States bushels.
20 hundredweight (2240 pounds) = 1 ton.

Nautical Distances

6 feet = 1 fathom.
120 fathoms = 1 cable.
6080 feet = 1 knot.
3 knots = 1 league.

Sea Water Weights

1 United States gallon = 8.58 pounds.
1 Imperial gallon = 10.27 pounds.
1 cubic foot = 64 pounds.
35 cubic feet = 1 ton.

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SECTION XXIV

LUBRICATION

The problems of lubricating refrigerating machinery and of selecting a suitable oil involve many variables. In centrifugal compressors, the bearing surfaces are normally not subjected to contact with the refrigerant and any lubricant which will work successfully in high-speed bearings is satisfactory for such service. Open-crankcase type reciprocating compressors use one type of lubricant for crankshaft, connecting rod and crosshead bearings, whereas another type is employed for cylinder lubrication.

The general requirements of a lubricating oil are:

(1) It should supply a continuous film of lubricant between the moving part and the bearing surface.

(2) It should possess very little friction between the particles of oil itself.

(3) The body must be sufficient not to squeeze out under heavy pressure.

(4) The temperature resistance should be sufficient to meet viscosity and vaporizing limitations.

(5) It should not be corrosive and should not react with the vapor medium or metal parts.

(6) It should have good keeping qualities.

Lubricating oils may be classified by the source of origin. Such a classification would include:

(1) Vegetable oils—those oils of vegetable origin, such as castor oil, linseed oil, and cottonseed oil.

(2) Animal oils—those of animal-fat origin, such as tallow, lard, fish oil and sperm oil.

(3) Mineral oils—those of crude-petroleum origin, such as common machine oil, engine oil, and automobile cylinder oil.

Vegetable oils never have been very satisfactory for lubrication. Time changes their properties. Old vegetable oils become gummy and thick and most of them readily become rancid.

Animal oils are the best lubricants we have from the standpoint of oiliness. A small quantity of animal oil added to mineral oil often greatly improves the lubricating quality of the mineral oil. The two principal disadvantages of the animal oils as lubricants are their poor keeping qualities and the relatively small supplies available.

Mineral oils are a distillation product of the petroleum industry and they can be produced with a wide range of properties and at a uniformly low price. Their keeping qualities are excellent.

Table 24–1 shows the order in which the various products secured from paraffin-base crude petroleums are distilled off. First, the ethers are given off at the lowest distillation temperature; then, in order, we have gasoline, kerosene, distillate and the heavier uel oils; then we have the lubricating oils, including the light spindle oils, engine cylinder oils, and engine bearing oils, with a paraffin residue remaining.

TABLE 24–1. PRODUCTS DISTILLED FROM PARAFFIN BASE CRUDE PETROLEUM

Products Given Off	Baumé Gravity, degrees
Gaseous ethers	105–85
Gasoline	85–48
Kerosenes	47–40
Distillates	39–30
Spindle oils	35–28
Fuel oils	30–25
Cylinder and engine oil	28–20

Vaseline is a by-product made up from the residue of the cylinder stock.

Most of the oils from the eastern part of the United States have a paraffin base, while those of the western section have an asphalt base. A similar table might be presented for the distillation of asphalt-base crude petroleum as has been presented here for the paraffin-base crude petroleum. The essential difference in such a table would be in the residue.

The gravity of oil is measured on the Baumé scale. On the standard hydrometer scale the specific gravity of water is one. On the Baumé scale the gravity of water is 10°. On the standard hydrometer scale, as the liquid gets lighter in weight per unit volume, the specific gravity is designated as less than one, while on the Baumé scale as the liquid gets lighter in weight per unit volume, the gravity is designated as more than 10°. Thus, spindle oils on the standard hydrometer scale are about 0.85 specific gravity, whereas on the Baumé scale they are about 33°.

TABLE 24-2. COMPARISON OF BAUMÉ AND SPECIFIC GRAVITY SCALES

Baumé Degrees	Specific Gravity	Baumé Degrees	Specific Gravity
10	1.0000	35	0.8484
11	0.9929	36	0.8433
12	0.9859	37	0.8383
13	0.9790	38	0.8333
14	0.9722	39	0.8284
15	0.9655	40	0.8235
16	0.9589	41	0.8187
17	0.9523	42	0.8139
18	0.9459	43	0.8092
19	0.9395	44	0.8045
20	0.9333	45	0.8000
21	0.9271	46	0.7954
22	0.9210	47	0.7909
23	0.9150	48	0.7865
24	0.9090	49	0.7821
25	0.9032	50	0.7777
26	0.8974	55	0.7567
27	0.8917	60	0.7368
28	0.8860	65	0.7179
29	0.8805	70	0.7000
30	0.8750	75	0.6829
31	0.8695	80	0.6667
32	0.8641	85	0.6512
33	0.8588	90	0.6364
34	0.8536	95	0.6222

The most severe and varying service conditions are encountered in the lubrication of enclosed crankcase machines, since the oil is at all times in contact with the refrigerant. It must lubricate the cylinders and piston pins at moderately elevated temperatures: the crankshaft bearings and crankpins at a somewhat lower temperature receive the same oil; in addition it must flow readily through restricted passageways in the coldest portion of the system. These requirements are unique, since suitable viscosity for lubrication at high temperature usually implies high viscosity at low temperature. General properties of a satisfactory lubricant for enclosed reciprocating compressors or for cylinder lubrication are:

(1) Chemical inertness toward refrigerants, water and oxygen.
(2) Heat stability.
(3) Suitable viscosity at maximum cylinder wall temperature.
(4) Must remain liquid at evaporator temperature.
(5) Low vapor pressure.
(6) Freedom from acids and other compounds which attack metals.

Chemical inertness is necessary to prevent combination with substances which are in contact with the lubricant. Animal or vegetable oils combine rapidly with ammonia to produce soaps; hence, oil for ammonia compressors should be entirely of mineral origin. Unsaturated oils will combine chemically with certain refrigerants and will oxidize readily, with the formation of acid and sludge.

Reciprocating compressors are equipped with air-cooling fins or water jackets; hence, the oil film upon the cylinder walls is seldom exposed to temperatures in excess of 200° F. However, oil spray or vapor is not in contact with the cylinder walls but is subjected to the much greater temperatures which are attained during compression. Under these conditions unstable oils decompose to form carbon or sludge and are rapidly oxidized in the presence of any air which may have leaked into the low side of the system.

The carry-over of oil from the compressor to the condenser and evaporator of a refrigerating system has been the source of many difficulties. If the lubricant is completely insoluble in liquid refrigerant, it may be excluded from the evaporator by suitable separating devices in the receiver. However, oils are more or less soluble in all common refrigerants and are completely miscible at ordinary temperatures with hydrocarbons and the halogenated hydrocarbons such as methyl chloride and the Freons. Thus, if any oil enters the condenser, a portion will eventually find its way into the evaporator in spite of traps in the receiver or liquid line. Unless some means is provided to continually remove the lubricant from the evaporator, it will accumulate until operation is impeded. With ammonia and other refrigerants in which oil is soluble to a limited degree, the viscous film formed upon evaporator surfaces impedes heat transfer and the evaporating liquid may foam excessively. The solution of oil in hydrocarbon or halogenated refrigerant results in an increase of the boiling point, thus making it necessary to operate at lower suction pressure, decreasing the efficiency. A minor waste of refrigeration is the sensible heat carried into the evaporator by oil mixed with the liquid refrigerant.

It is too often assumed that the carry-over of lubricant from the compressor to the condenser is entirely due to oil pumping or to entrainment of spray or oil fog by the discharged vapor. Although it is not denied that these factors are important, such a carry-over will be almost completely recovered by efficient separators in the compressor discharge line. However, some recent research shows that large quantities of oil may leave the compressor as vapor which cannot be recovered by any type of gas-liquid separator. It is pointed out that any oil whatsoever possesses a vapor pressure and that this pressure increases with a rise in temperature. Thus evaporation occurs from the oil film on the cylinder wall and in case any oil is sprayed into the gas, partial evaporation will take place from the heat of compression. Liquid lubricant passing through the discharge valve and into the hot discharge line will be partially or completely vaporized and the vapor will be liquefied in the condenser along with the refrigerant.

To minimize oil carry-over, the lubricant should have the minimum possible vapor pressure at the higher temperatures. The flash points of oils are approximate measures of the temperatures of which their vapor pressures are equal. However, it is erroneous to assume that the vapor pressure is zero at lower temperatures and that no lubricant will be volatilized if the operating temperature is held below the flash point of the oil.

SECTION XXV

FANS

General. Fans are available in the axial, or propeller, and the centrifugal, or radial, types.

Axial, or propeller, fans, as their name implies, have their direction of discharge parallel to the fan shaft, and for the most part the suction stream of air entering the axial fan tends to be in the direction parallel to the shaft.

Centrifugal, or radial, fans discharge radially from and at right angles to the shaft by centrifugal force. The air enters the fan in an axial direction, then turns at right angles to the shaft and enters the spaces between the blades of the fan. The flow of gas or air is radial after it has turned at right angles as it passes outward by centrifugal force. Both the pressure and the velocity increase as the gas moves toward the outer periphery of the rotating fan.

AXIAL FANS

When the axial blade is flat, it is termed a disc fan. When the blades are given a twist to a warped surface they are classified as propeller fans.

Axial fans are commonly used without shrouds or piping ducts. They are installed in outside walls to exhaust air from a building, in rooms to recirculate air and in many special applications where a straight-line flow of air is desired. Unit coolers and unit heaters are typical of applications of the straight-through movement of air to which axial fans are well adapted.

The development of the airplane propeller has provided much information for the design of propeller fans. The modern axial-flow fan is patterned after the best propeller design including guide vanes to prevent air turbulence and streamlined housing of the motor to eliminate air resistance over the driving mechanism and fan hub. These refinements have made axial type fans competitive with centrifugal fans in efficiency. They can be highly recommended in the low-pressure field of application, where a straight-line flow of air is desirable.

Axial flow fans are built with as few as two blades and may have as many as twenty-four. The trend is toward a fewer number of blades and more guide vanes. There is considerable evidence that with increased care in design of the axial type fan it can compete with the centrifugal type in efficiency for pressures as high as 3 or 4 in. of water.

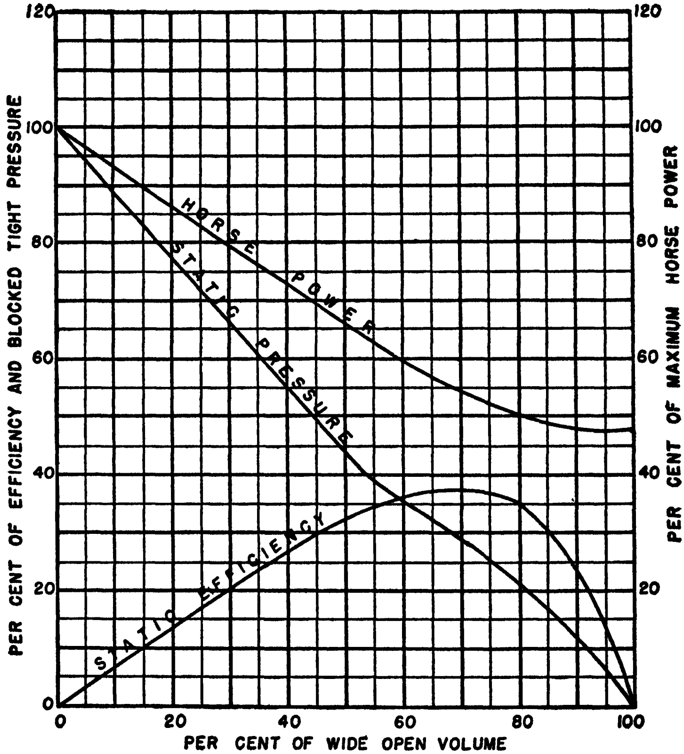


FIG. 25–1. Characteristics of an axial-flow disc type fan.

Axial flow fans are available in many types of layout design and their selection should receive the same care as is customary for centrifugal fans. Due to their simpler construction they do lend themselves to more standardization than is possible with the centrifugal fan, but such standardization does not justify less care i the selection of the right fan for the job to be done.

For low initial cost, for small space requirements, and for plan standardization the axial flow fan has definite advantages. It ca compete with other fans in efficiency and in noiseless operation For all applications where a straight-line air flow is desired, the should be investigated.

Choice of Type of Axial, or Propeller, Fans. Propeller type fan with pitch angles up to 20° give a performance that is stabl

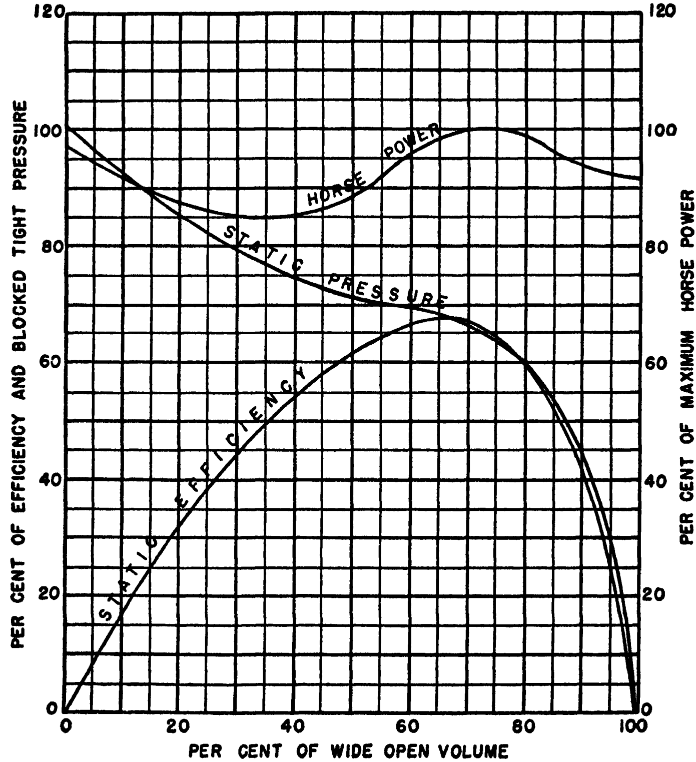


Fig. 25–2. Characteristic of an axial-flow propeller type fan.

throughout the full range of their characteristic curve. Propeller type fans with pitch angles greater than 20° are unstable over a limited range of operating conditions.

Advantages of Steep-pitch Propeller Blades.

(1) Greater capacity for a given size.

(2) Are less noisy than small-pitch angle blades.

(3) Can be built for high pressures.

Disadvantages of Steep-pitch Propeller Blades.

(1) Instability.

(2) Less efficient than small-pitch angle blades.

Advantages of Small-pitch Propeller Blades.

(1) High efficiency.

(2) Stable operation.

Disadvantages of Small-pitch Propeller Blades.

(1) Low capacity.

(2) High speed.

CENTRIFUGAL FANS

The centrifugal fan is designed to move air through a duct or piping system, especially where high pressures are required.

Centrifugal fans may be purchased in a variety of blade and casing designs. Common classifications of centrifugal fan blades are (1) forward curved blades, (2) radial blades, and (3) backward curved blades.

Advantages of Forward-curved Blades.

(1) For the same revolutions per minute and diameter of the three types of blades the forward-curved blade produces a higher velocity of air with respect to the fan outlet. In other words, for the same fan diameters and speeds the forward-curved blade moves a greater quantity of air. They are called also volume fans because they will handle more air than any other type for the same speed, pressure and efficiency.

Disadvantages of Forward-curved Blades.

(1) This type fan is inherently unstable; that is, at constant revolutions per minute the pressure produced in the duct decreases over portions of the load range with decrease in volume.

(2) Inefficient operation in carrying a parallel load with a second fan of the same type, both fans discharging into the same duct.

(3) An overloading horsepower demand develops on one fan motor in the event of failure of a second fan when the two are discharging into the same duct. In selecting motors for this type of fan for parallel operation this overload factor must be considered.

Advantages of a Radial or Straight-blade Fan.

(1) At constant revolutions per minute the pressure produced in the duct remains constant with decrease in volume or load.

(2) Designed for large capacity rather than high efficiency.

(3) Stable as to static pressure.

Disadvantages of a Radial or Straight-blade Fan.

(1) Unstable where total pressure controls the application of the fan.

(2) An overloading horsepower demand develops on one fan motor in the event of failure of a second fan when the two are discharging into the same duct.

Advantages of Backward-curved Blades.

(1) Can be used efficiently for parallel operation.

(2) Inherently stable.

(3) Will not overload the driving motor in the event of failure of a second fan when the two are discharging into the same duct.

(4) Is less susceptible to pulsation under same conditions when pulsation is most severe in forward-blade fans.

Disadvantages of Backward-curved Blades.

(1) At constant revolutions per minute the discharge pressure of this type fan increases with decrease in load or volume. This stability characteristic may be undesirable in some applications.

(2) For the same diameter and speed of the three types of fans, the backward-curved blade type produces the lowest velocity; hence, quantity of air with respect to the fan outlet.

Choice of Centrifugal Fan Type. Choosing the type of centrifugal fan for a specific application is determined by *centrifugal fan characteristics.*

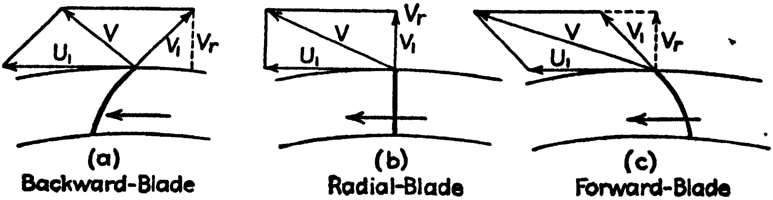


FIG. 25–3. Velocity diagrams for three types of blades.

The analysis of the three types of blading are plotted to aid in the selection of the desired fan type (Figure 25–3), in which:

V = the actual or absolute air velocity of the fan discharge, in feet per second. In the velocity diagram, V is the resultant of V_1 and U_1.

V_1 = the velocity of air relative to the fan wheel, in feet per second. The direction of V_1 is tangent to the tip of the blade; therefore, the direction of V is constant for a given blade and speed.

U_1 = rotative speed of the impeller.
r = radius of fan wheel to tip of blade.
V_r = volume vector.

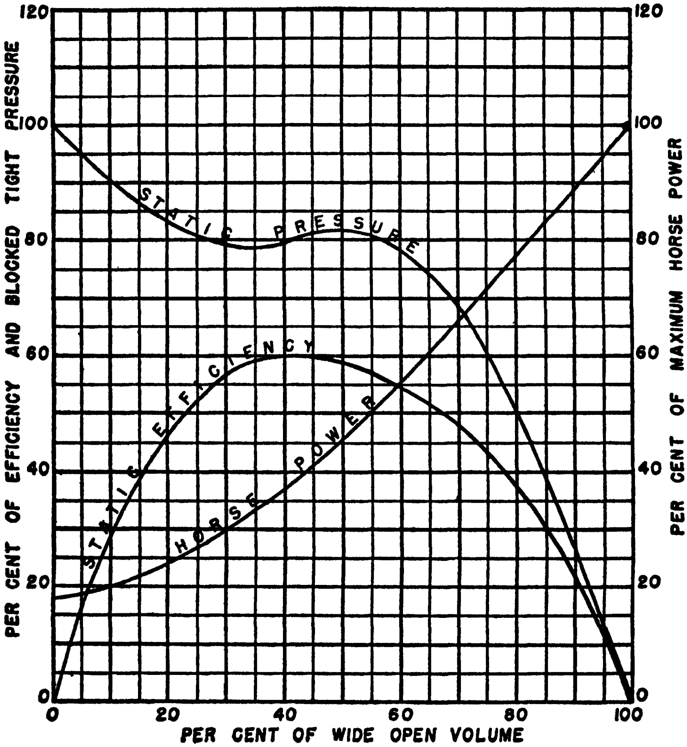


FIG. 25–4. Characteristics of a centrifugal fan, blades curved forward.

The pressure characteristics of the three types of blade tips are:

(1) The pressure of a backward-curved blade increases with decrease in volume at constant speed.

(2) The pressure of a straight- or radial-blade fan is constant with decrease in volume at constant speed.

(3) The pressure of a forward-curved blade decreases over part of the volume range with decrease in volume at constant speed.

The output of air for a given fan-tip speed and fan size will be greater for a forward-curved blade fan than for a straight-blade fan and, in turn, the air discharged from a straight-blade fan will be greater than that of a backward-curved blade for the same speeds and fan size.

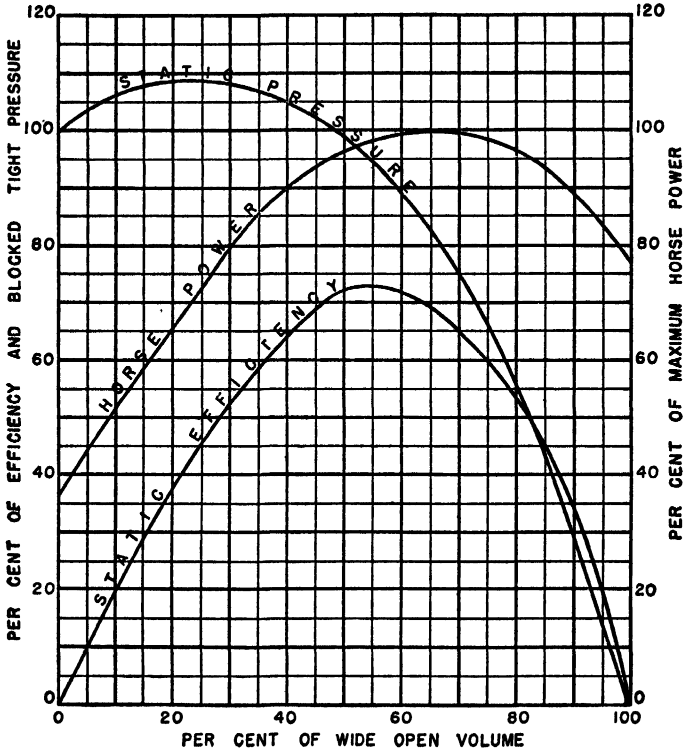


Fig. 25–5. Characteristics of a centrifugal fan, blades curved backwards.

An increase in pressure with a decrease in volume is the requirement for stability of fan operation. Other desirable features that are essential to some fan installations are (1) freedom from pulsation, (2) characteristics that will reduce fan overloading to a minimum and (3) adaptability to operation in parallel and discharging into the same duct without overloading when one fan stops operating.

Loading and Unloading of Centrifugal Fans. A decrease of the volume of air discharged by a fan decreases the horsepower required for its rotation. The air discharged may be reduced by restricting the suction inlet or the discharge outlet. A resistance of any nature placed in the suction or discharge will reduce the air delivered and likewise lower the horsepower requirements.

An increase in the length of the intake pipe or discharge pipe or a filter placed on either the suction or discharge has the effect of reducing the area of the lines and lowering the horsepower requirements. Conversely, a shortening of the suction or discharge lines results in a larger air volume discharge. This places a heavier demand on the motor without any change in speed.

When an installed felted filter is new and permits a free movement of air through the fibers, much more air can be delivered than with a clogged, dirty filter. The result is that, with the clogging of the filter, the air available is decreased and likewise the horsepower demand on the motor.

Some inexperienced engineers make the mistake of purchasing a fan on the basis of free discharge, then installing the unit on a service requiring several resistances to the free flow of the air. The capacity of the fan as used is thus reduced below the values given in the specification for free discharge and may be inadequate.

LAWS OF FAN PERFORMANCE

Both propeller and centrifugal type fans obey the following fan laws. These laws are based on the fundamental consideration that fan efficiencies remain constant. When one or more conditions change, the rest must change accordingly.

For a Given Fan Size, Duct or Open System and Gas Density When Speed of the Fan Varies.

(1) Capacity varies directly as the speed.
(2) Pressure head varies as the square of the speed.
(3) Horsepower is directly proportional to the cube of the speed.

When Pressure in the System Varies.

(4) Capacity varies as the square root of the pressure.
(5) Speed varies as the square root of the pressure.
(6) Horsepower varies as the three halves power of the pressure.

When Fan Sizes Vary but Pressure and Density Are Constant.

(7) Capacity varies as the square of the diameter.
(8) Horsepower varies as the square of the diameter.

When Density Varies and Pressure is Constant.

(9) Speed, capacity and horsepower vary inversely as the square root of the density; that is, inversely as the square root of the barometric pressure and directly as the square root of the absolute temperature.

When Density of Gas Varies but Volume and Speed Are Constant.

(10) Horsepower varies directly as the gas density or barometric pressure and inversely as the absolute temperature.

(11) Pressure varies directly as the barometric pressure and inversely as the absolute pressure.

When Density of Air Varies but Weight of Gas is Constant.

(12) Capacity, speed and pressure vary inversely as the density; that is, inversely as the barometric pressure and directly as the absolute temperature.

(13) Horsepower varies inversely as the square of the density; that is, inversely as the square of the barometric pressure and directly as the square of the absolute temperature.

When Both Temperature and Pressure Vary.

(14) Capacity and speed vary as

$$\sqrt{\text{pressure} \times \text{absolute temperature}}.$$

(15) Horsepower varies as

$$\sqrt{\text{pressure}^3 \times \text{absolute temperature}}.$$

Fan Capacity and Efficiency Computations. For normal air or gas flow the fundamental fluid flow equation $q = av$ is used in the determination of the discharge of a fan; or, cubic feet per minute of gas flow = area of the duct in feet × the velocity of air or gas in feet per minute, or $Cfm = av$.

The velocity of air at normal room temperature, when measured by a water gage, can be computed approximately by multiplying the square root of the water gage velocity pressure reading by 4100, or

$$\text{Velocity} = 4100\sqrt{\text{Water gage velocity pressure reading in inches}}.$$

Since the density (weight of a cubic foot) of the air or gas changes with changes in temperature, a more accurate determination of velocity can be computed as follows:

$$\text{Velocity} = 1096\sqrt{\frac{\text{Water gage velocity pressure reading in inches}}{\text{Specific weight of gas per cubic foot}}}.$$

TABLE 25–1. SPECIFIC WEIGHTS OF SOME COMMON GASES AT 32° F. AND STANDARD BAROMETER

Name of Gas	Specific Weight, lbs. per cu. ft.
Air	0.07428
Ammonia	0.051
Butane	0.16194
Carbon dioxide	0.12344
Ethane	0.08379
Flue gas (average)	0.0840
Methane	0.0447
Sulphuric dioxide	0.17870

The *static efficiency* of a fan is a ratio of the power necessary to move the actual weight of air against the static pressure or head as compared to the horsepower input into the fan rotor.

$$\text{Static efficiency} = \frac{\left\{\begin{matrix}0.000158 \times \text{cu. ft. of air delivered per min.} \\ \times \text{ static pressure in in. of water}\end{matrix}\right\}}{\text{Horsepower input to rotor}}$$

The *total efficiency* or *mechanical efficiency* is the ratio of the power necessary to move the actual weight of air against the total fan pressure or head as compared to the horsepower input into the fan rotor.

$$\text{Mechanical efficiency} = \frac{\left\{\begin{matrix}0.000158 \times \\ \text{cu. ft. of air delivered per min.} \times \\ \text{total pressure in in. of water}\end{matrix}\right\}}{\text{Horsepower input to rotor}}.$$

The *air horsepower* of a fan is the horsepower that the air discharged represents. The air horsepower of the fan divided by the brake horsepower equals the mechanical efficiency.

To find the air horsepower, multiply the cubic feet of air discharged by the total pressure of air in inches of water and this by 0.000158 or

$$\text{Air horsepower} = 0.000158 \times \text{cu. ft. of air delivered per min.} \times \text{total pressure of air in in.}$$

Problem. **Find the air horsepower of a fan delivering 90,000 cu. ft. of air per min. at 5 in. total impact pressure.**

Solution. **Air hp. = 0.000158 × 90,000 × 5**
Air hp. = 71.1 hp.

Determination of Static, Velocity and Total Pressures of Fans. Three air pressures are always considered in measuring air discharge. There is a compression pressure produced by the air being compressed by the fan. This is called the *static pressure.* There is a *velocity pressure* due to the velocity of the moving air. The two above pressures taken together make up the third pressure, usually specified as the *total,* or *impact, pressure.*

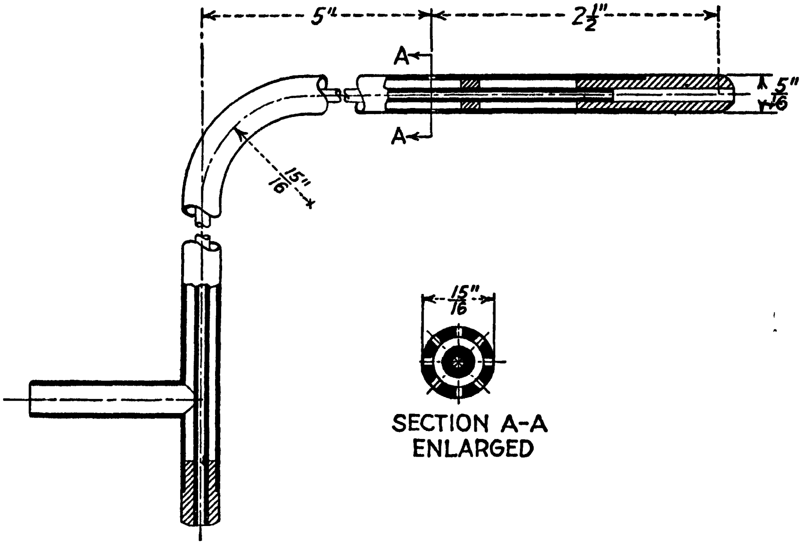
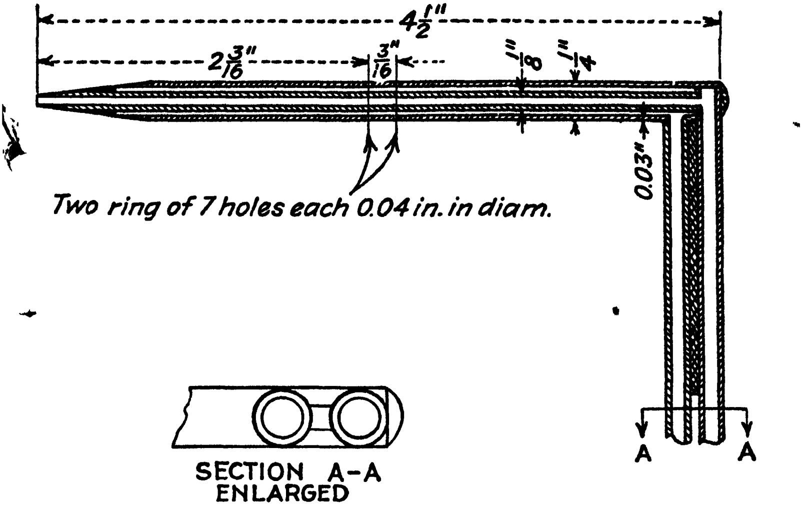


Fig. 25-6. Standard pitot-static tube for use in fan tests.

Static, velocity, and total pressures can be determined by using a bent tube, open at one end and attached to an open-sight calibrated water gage at the other end. The open end of the tube should be inserted in a straight run of discharge pipe of the same diameter.

For best results, the tubes should be placed at a point in the pipe that is eight to ten times the duct diameter from the fan outlet. The open end of the tube facing the air stream should be parallel to the stream flow.

For more accurate measurements, a single pitot tube combining the above tubes can be used. The outer ends of the pitot tube can be connected to the same water gage. The reading of the water gage in this case gives the velocity pressure, P_v, directly.



COMBINED PITOT TUBE FOR MEASUREMENTS OF AIR AND GASES

Fig. 25-7.

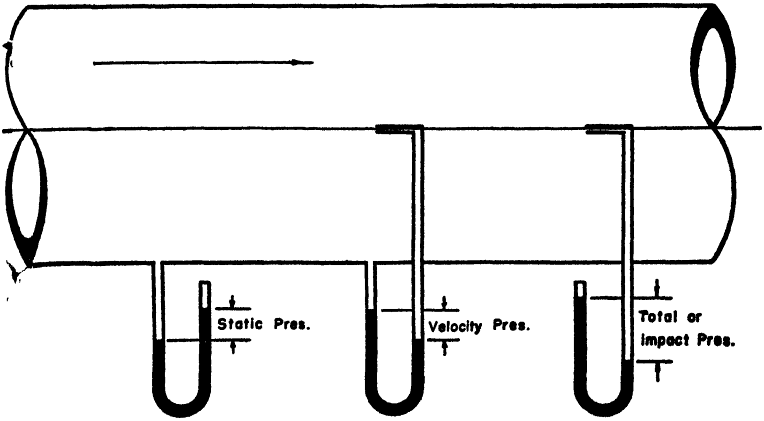


Fig. 25-8. Manometer connections for measurement of static and velocity pressure.

In taking readings of the velocity and total pressures in small air ducts, approximate results can be secured by taking the velocity and total pressures by reading the pitot values for the center of the pipe and multiplying these values by 0.81 to obtain the average velocity and total pressure. The velocity pressure at the center of the pipe is higher than the true average and must be corrected by this factor.

For accurate results, a pitot tube traverse should be made of the duct to obtain the velocity and total pressures. For a square duct, the total area is divided into a number of small squares or rectangles and a reading taken in the center of each. For round ducts, a cross section is divided into a number of concentric zones of equal area and four readings taken in each area, two readings being taken at the center of the concentric ring on the horizontal and two on the vertical of each area. By this process an accuracy within 1% can be secured in air discharge measurements.

SECTION XXVI

PUMPS AND INJECTORS

Reciprocating Pumps

The reciprocating pump is the most common type on the market. Its simplicity and low cost are largely responsible for its wide adoption.

The reciprocating pump may be the *direct-acting* or the *flywheel* type. When the pump is made up for direct piston drive without a flywheel it is classified as a direct-acting reciprocating unit. When the pump is equipped with a flywheel to make possible an earlier cutoff of the steam and permit the inertia of the wheel to assist it after the pressure of the steam has been cut off, it is classed as a flywheel reciprocating pump.

When direct-acting pumps are steam driven, they may be designed with one steam cylinder as simplex units or with two cylinders of the same diameter, in which case the pump is called duplex. In larger units there may be two steam cylinders of different sizes designed for compound operation either tandem or side by side.

On the water end, simplex, duplex, and compound pumps may be piston operated or may function with a plunger. Plunger pumps in turn may be either center packed or outside packed.

In both the simplex and the duplex direct-acting pumps, the steam consumption is high. Much better economy can be obtained by compounding the steam cylinders, but this increases the maintenance problems and the original cost of the pump.

The simplex pump has less working parts than the duplex type and this usually means less repair expense. The movement of the steam valve of the simplex pump is dependent entirely upon the stroke of the one piston, which reduces the tendency of the pump to slam or "short stroke."

The duplex pump has the distinct advantage of supplying a more continuous discharge than is possible with the simplex. The principal advantage of the duplex pump is, however, its ability to start from any position. The stroke of the piston of one of the cylinders operates the valve controlling the admission of steam into the other cylinder.

Piston and Plunger Pumps. On the steam end, piston and plunger pumps do not differ. Both are made in simplex and duplex types and with or without tandem or side-by-side compound cylinders.

The steam end is usually a counterbored cylinder equipped with a cast-iron piston fitted with cast-iron piston rings. The maintenance of the steam end of a pump is similar to that of steam engine cylinders and pistons.

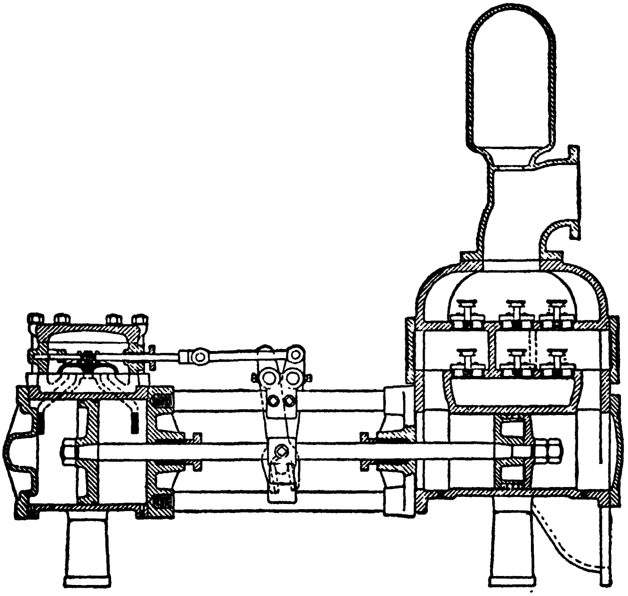


FIG. 26–1. Sectional view of piston pump with air chamber.

On the water end, the piston pump and the plunger pump are quite different. The piston pump is built with a piston in the water cylinder, much like the piston on the steam end, except that the follower is built to be packed with a hydraulic packing.

The packing used for piston pumps is a rubber and fabric hydraulic-molded product. The piston is of spool form, with the outer end of the spool removable so that the rings of packing can be readily slipped into position when the head of the water cylinder is removed. When oils are to be pumped, metallic packing is substituted for the fabric.

The water end of the plunger pump is much heavier than that of the piston pump. Two types of plunger pumps are manufactured. One type is made up with two plungers per cylinder, one plunger in each end. The inner end plunger is driven directly by the piston rod, whereas the outer end plunger is driven from side rods. The two plungers are placed on the ends in glands surrounding the plunger at the center of the water end and the displacement chambers are at the cylinder ends. This type has the advantage over the end packing in that it requires less space, but it is not as accessible. Commercially this pump is known as the "outside center-packed plunger pump."

Comparative Advantages of Plunger and Piston Type Pumps. Reciprocating plunger pumps have their packing glands in full view, thus permitting close observation at all times. The packing glands are readily accessible, so that they can be tightened up while the pump is in operation. To obtain these same results with the piston type requires the removal of the cylinder head, and this cannot be done without shutting down the pump for some time.

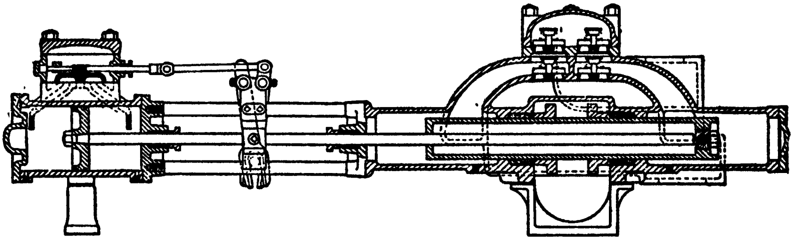


Fig. 26–2. Sectional view outside center-packed plunger pump.

Piston pump leakage, except at the piston and glands, is never visible. This permits maintaining the base below the pumps in drier condition, as the leakage is all within, instead of without. Outside-plunger pumps should be so installed that the leakage will be drained directly to the sewer to prevent flooding the floor.

Plunger pumps should not be used in locations where there is excessive dust floating in the air. The plunger will carry the solid matter into the gland packing and cause excessive wear and friction.

The mechanical friction loss of new, well-packed plunger pumps is about 5% greater than that of new, well-packed piston pumps However, in practice this comparison does not necessarily hold. There is a great tendency for operating engineers to pack piston pumps too tightly, with the idea of eliminating leakage. It is not uncommon to find inexperienced engineers packing the water piston tight "to allow for wear." Very good results can be obtained by making up a wooden form just the size of the piston spool and cutting the packing exactly to fit this spool on a 45° bevel. The packing can then be soaked in hot water for a few hours before installing, if it is to be used for pumping hot water.

In general, the plunger pump is to be recommended for plants that have efficient, high-grade supervision and little dust. For the plant that operates with poor supervision, the piston pump is more desirable.

Power-driven Plunger Pumps. Power-driven plunger pumps have some admirable characteristics. As outlined above, the steam-driven pump is not a highly efficient unit. Where power is available either from a line shaft or from a separate motor, the installation of a power-driven pump is often more satisfactory than a steam-driven pump.

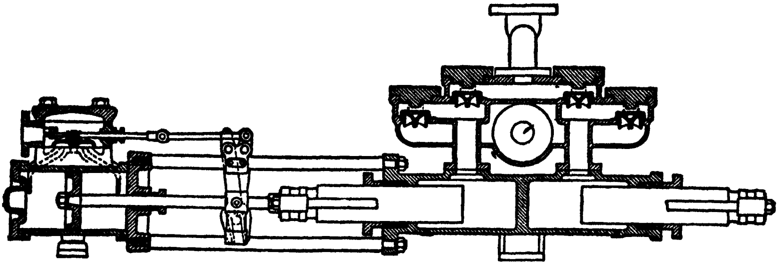


FIG. 26–3. Sectional view outside end-packed plunger pot valve pump.

If the connection is to a line shaft or engine running at constant speed, it will be necessary to bypass the pump from the discharge to the suction line in order to take care of the fluctuating demand when used for variable loads like boiler feeding.

Pump Governors. For many applications it is desirable to maintain virtually constant pressure in the discharge line. Pump governors can be obtained for this duty on steam-driven units. The pump governor is essentially a balanced valve on the steam main leading to the pump steam cylinder, with a water connection to the pump discharge.

Setting the Steam Valves. General instructions can be given for setting virtually all types of duplex steam pumps. For setting the simplex valves so many different valve mechanisms have been developed, some of them adjustable and others not, that the authors recommend in every case that the owners of simplex pumps secure complete information for these pumps from the manufacturer.

To Set the Duplex Pump Valves.

(1) Open the drain cocks beneath the cylinders and drain.

(2) Set both pistons in midposition. This can be done by moving the piston rod to the head end of the steam cylinder until the piston strikes the cylinder head. Take a scriber and mark the piston rod close up to the steam-end packing gland. Now move the piston rod until the piston strikes the opposite end. Again mark the piston rod at the steam-end packing gland. Divide the distance between these two marks on the rod in half and mark this midpoint. Now move the piston rod back until this midpoint is flush with the face of the steam-end packing gland. Do this for both pistons.

(3) Remove the steam chest cover and set both valves centrally over their respective steam ports. With some pumps this must be done by removing the connecting pins at the valve stem knuckles and adjusting the length of the valve stems by screwing in or out. With other pumps the adjustment can be made on movable lugs within the valve chest that are mounted on the valve stems.

(4) The lost motion between the lugs and the valve should be equalized before adjustment is complete. When the valve setting is done by moving or turning the valve rod, there is no question about the amount of lost motion to allow, since all lugs are stationary. When the adjustment is made by movable lugs, it may be necessary to determine by trial the correct amount of lost motion required by the pump. The strokes of most duplex pumps depend on the amount of lost motion in the valve movement.

When correctly set, the pistons should be in midposition, and the valves should be in midposition with equal clearance or an equal amount of lost motion on both ends of the valve when the valve knuckles are connected.

Pump Slip. For every stroke of the pump plunger there is a displacement equal to the length of the stroke times the area of the pump piston. This is known as the plunger displacement. But when the pump is running it does not discharge as much water as could be placed in the volume displaced by the plunger. The actual displacement is always a few per cent less than the plunger displacement. This loss of each stroke is known as the *slip*. It is usually expressed in per cent. A pump having 10% slip is one in which the actual water discharged is only 90% of plunger displacement.

In most water plants the slip will vary from 5% to 10% in new pumps and from 15% to 30% in old pumps.

By closing the pump discharge valve, placing a gage on the discharge side and opening the steam valve to give a movement of the pump sufficient to maintain the operating pressure, an index can be obtained of the slip or lost action of the pump.

Pump Slip Data.

New pumps	2- 5%
Used pumps in good repair	8-15%
Worn pumps	20-40%

Suction Lift of Reciprocating Pumps. Since reciprocating pumps are of positive displacement they are self-priming. When the pump is located at high altitudes it will not lift as high as at sea level. In general, the increase of elevation of each 1000 ft. will reduce the probable lift by one foot. The water temperature will affect the lift very greatly. Although the theoretical suction lift is 32 ft. at 60° F., 30 ft. at 120° F. and 17 ft. at 180° F., the actual lift to be expected in practice would be 22 ft. at 60° F. at sea level, 8 ft. at 120° F., at 180° F. There should be a minimum of 6 ft. of positive head on the suction side if the pump is not to become vapor bound.

CENTRIFUGAL PUMPS

Centrifugal pumps may be given several different classifications and definitions. Strictly speaking, a centrifugal pump is built with an impeller that rotates on the inside of a pump case and has its intake at the center of the impeller, and discharges by centrifugal force, throwing the liquid to the periphery of the rotating impeller through the blades or openings and then out into the piping systems.

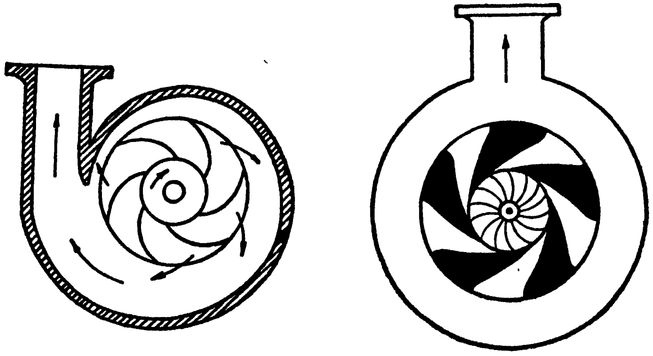
If the pump casing is designed with an enlarging passageway to receive the water or liquid from the rotating impeller, the centrifugal pump is classified as a guide-vane or turbine centrifugal pump.

A pump that is often classified as a centrifugal type but is more strictly an axial-flow unit is the propeller pump. These pumps appear on the market under other names such as spiral pumps, screw pumps and straight-flow pumps, but fundamentally they are axial-flow pumps with an impeller or propeller patterned much like a ship propeller.

Another method of classification of a centrifugal pump is to indicate it as a single-stage or a multi-stage unit. The centrifugal pump lends itself to staging for high pressures; thus, multi-stage pumps are a common answer to a high pressure need.

This staging possibility is very useful where it is desirable to use a centrifugal pump as a pressure booster. Two centrifugal pumps can be installed in series to pump against the sum of the separate heads for which each pump was designed. Where an inadequate liquid pressure condition exists, a centrifugal pump may be designed to receive the liquid at this pressure and boost it to the desired pressure. The pressure of the first unit is conserved as it enters the suction of the centrifugal pump and the liquid in turn is boosted to the higher pressure.

Volute Pumps. The volute pump adapts itself to delivering large quantities of water at low heads, such as is common in spray pond and spray tower service and in general purpose low-head pumping.



"Volute" Type "Diffuser" Type

FIG. 26-4. Centrifugal pumps.

The impeller blades are curved backward, away from the direction of rotation. The suction of the pump is designed to admit the water near the center or eye of the impeller and the impeller blades, then discharge it outward to the periphery. The design of the volute or spirally shaped casing and its component impeller is such as will produce a stream flow with a minimum of friction and eddy loss.

Turbine Pumps. The turbine pump or guide-vane pump is the evolution of a pumping unit needed for high rotative speeds and high pumping heads. The name "turbine pump" was attached to it because the guide vanes and the impeller gave the appearance of a water turbine which was operated in the reverse process of discharging outwardly instead of receiving inwardly the water or fluid medium.

Some Characteristics of Centrifugal Pumps.

(1) When the speed is increased, the gallons delivered will increase in the same proportion. Thus, if the speed is doubled, the water discharged will be twice as great.

(2) When the speed is increased, the head will be increased in the ratio of the square of the speed. Thus, if the speed is doubled, the head will be four times as great.

(3) When the speed is increased, the horsepower requirements will be increased in the ratio of the cube of the speed. Thus, if the speed is doubled, the horsepower requirements will be increased eight times.

The quantity of discharge for a given type of centrifugal pump will vary as the diameter of the impeller for any given speed; the head pressure will vary as the square of the diameter of the impeller for any given speed, and the horsepower requirements will vary as the cube of the diameter for any given speed.

When the resistance to water flow on the discharge or on the suction side of a centrifugal pump is increased, the horsepower (which is the product of the weight of liquid pumped per minute times the head in feet against which the pumping is being done and this product divided by 33,000) will decrease. If the resistance of the suction or discharge is decreased so that more water will be pumped, then the pump horsepower will likewise increase.

If the pump were of the plunger, the piston or the rotary type and the resistance in the discharge were increased to the point of choking the line of discharge completely, either the pumps would have to stop or the discharge line would rupture. With a centrifugal type of pump the increase of resistance even to the point of closing the discharge line need make no change in the speed. The horsepower necessary to operate the pump would drop to the frictional resistance of rotating the pump impeller in a chamber of water at its inherent speed.

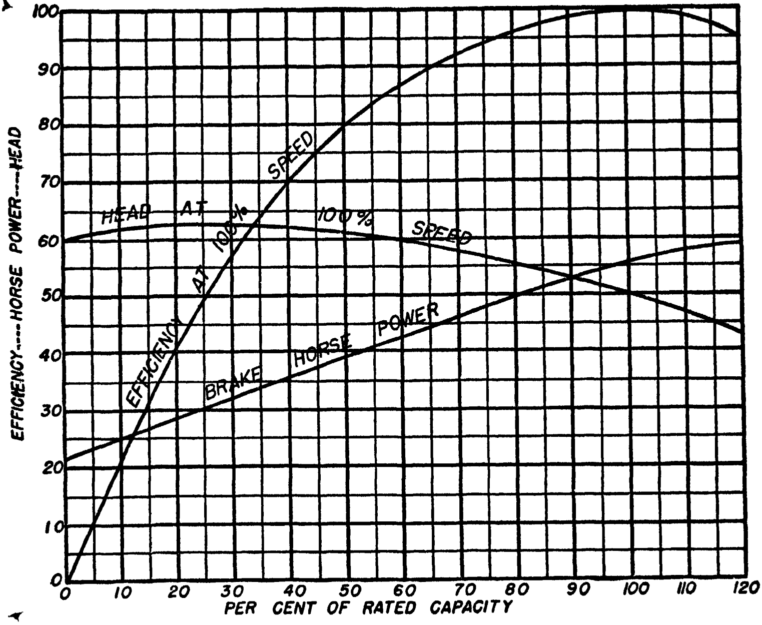


FIG. 26-5. Characteristics of a typical centrifugal pump.

The centrifugal pump should not be operated for any appreciable length of time with a closed suction or a closed discharge, since the water enclosed within the pump casing will have to absorb all of the frictional resistance and thus the pump will quickly overheat.

In contrast to this, if the suction lift or the discharge head is greatly decreased on any centrifugal pump, the load on the driving unit may increase to the point of overloading.

These characteristics of pumps of the centrifugal type should be closely observed. An increase in the length of the suction line or a similar increase in the length of the discharge line will decrease the water discharged, because the resistance to flow has been increased. The horsepower requirements of the pump will be correspondingly reduced.

When it is desired to use a centrifugal pump as a portable unit, as for fire-pump purposes, adaptable to pumping from roadside streams, either an auxiliary reserve water tank should be carried on the pumping truck for priming the centrifugal pumping unit or an auxiliary rotary pump should be supplied to give the centrifugal pump its necessary priming. In stationary service, similar devices can be employed to assure the pump immediately picking up its prime for the service desired.

Within recent years special designs which make this reserve priming water feature a part of the pumping unit have been provided. This gives the user a pump that is self-priming and still has all the desirable features of the centrifugal pump. Self-priming has been accomplished by providing a casing sufficiently large to hold a reservoir of water to perform the self-priming function.

Suction Lines of Centrifugal Pumps. Low suction lifts for centrifugal pumps are always desirable if they can be installed. For cold-water pumping, a maximum lift of 18 ft. on the suction side is recommended and if at all possible, this should not exceed 16 ft. The resistance of the suction pipe should be kept very low by using short suction lines of ample diameter and by avoiding sharp bends.

The suction line should always be graded upward to the pump suction inlet and great care should be exercised to have no air pockets formed by sagging pipe lines or downward looping of pipe between the water supply and pump. The intake end of the suction line should be far enough above the bottom of the pump sump to assure freedom from silt around the suction pipe, but it should be far enough under the low water level of the pump to prevent entrainment of air by suction swirls.

The centrifugal pump has the great advantage that it will function with water containing a high degree of silt or foreign matter. Water that would choke the valves of plunger and piston type pumps can be readily handled by centrifugal pumps. However, a strainer is a very good investment on the end of any centrifugal suction pipe to safeguard the pump system against needless abuse from foreign material eroding the impeller and pump casing. A strainer with a free area of four times the area of the suction pipe is suitable.

Plotted Characteristics of Centrifugal Pumps. The form of the efficiency, the head and the brake horsepower curves of a centrifugal pump when plotted against capacity will vary with impeller design, the head for which the pump was designed and the pump capacity. Typical characteristic curves show a minimum of brake horsepower when the pump is delivering no fluid. The head is at its maximum when the delivery is relatively small. As normally designed, the centrifugal pump reaches its maximum efficiency between 80% and 110% of capacity rating.

Closed-system Operation. In ice plants and cold-storage rooms many of the centrifugal pump applications are for so-called closed systems. This refers to the operation of the pump on a recirculated liquid that remains the same from hour to hour. The brine tank, the brine cooler, the water circulating system for a hotel or office building are all examples of closed systems. The centrifugal pump adapts itself very satisfactorily to this service. In the closed system the pump performs the function of circulating the liquid and delivering it back to its own suction. Its principal load is the overcoming of the friction of the system.

For this type of service there is very little change from day to day in the pumping head; thus a pump can be selected that will operate at a maximum of efficiency.

Condenser cooling water that is returned to the spray pond or cooling tower, although not functioning strictly on a closed system, can be circulated with a very high efficiency of pump performance, since the static head of the suction can be conserved. The principal losses are the friction load of the piping system and the losses through the spray or discharge nozzles.

Centrifugal Pump Inspection.

If the Pump Is Overloaded.

(1) Investigate the shaft and bearings.

(2) Determine if the suction lift has been reduced.

(3) Determine if the discharge head has been reduced.

(4) Test the viscosity of the liquid to see if it has been increased.

If the Pump Fails to Deliver.

(1) Has the suction line been lengthened excessively?

(2) Has the discharge line been lengthened excessively?

(3) Is some foreign material choking the suction?

(4) Is some foreign material lodged in the discharge or on the impeller?

(5) Is the suction line taking in air by failure to maintain sufficient submergence?

If the Pump Capacity Has Lowered.

(1) Look for air leaks in the packing glands.
(2) Examine the suction line for air entrainment.
(3) Determine if the impeller has been damaged.
(4) Is the viscosity too high?
(5) Is the temperature too high?

Deep-well Centrifugal Pumps. The deep-well centrifugal pump has found extensive use in refrigeration plants where an adequate supply of underground water is available but surface supplies of water are not. Deep-well centrifugal pumps received their initial extensive application for irrigation, but subsequent developments indicated their practicability for other water supply needs.

The power may be supplied either from a motor-driven power head at the top of the well hole, with the centrifugal unit submerged down in the well or, as in recent years, from a submersible motor built as a part of the complete pumping unit. This submersible type is lowered into the well and both pump and motor are operated beneath the water surface.

When the power is supplied through a power head at the top of the well, the designer must make provision for caring for the thrust and weight of the pumping unit within the well. When the power motor of the submersible type of pumping unit is built integral with the centrifugal pump, the complete unit is supported by the discharge main that rises from the centrifugal pump discharge. The electrical supply of the submerged type motor is delivered to the motor by cable installed on the outside of the discharge main but within the well casing.

Operational Precautions for Deep-well Centrifugal Pumps. The deep-well centrifugal pump is dependent for its lubrication upon the water pumped. A sandy water supply may prove very mostly in pump maintenance. In some regions where all of the water supply occurs in sand stratas, the maintenance of the sand screens within the well are more troublesome than the maintenance of the pumping unit.

Wells to be pumped from a power head at the top of the well hole should be checked for the straightness of the bore of the well. Wells that have been drilled with a slight curvature in the bore will experience a decided whipping of the drive shaft and in a short period of time the drive shaft may fail from flexure fatigue.

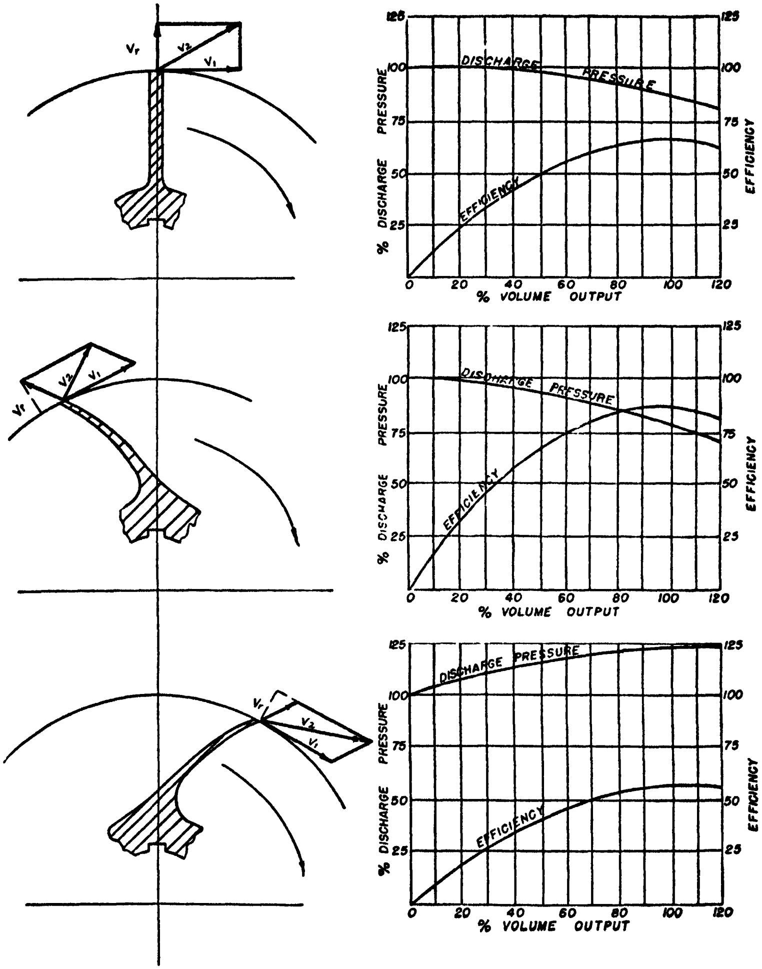


FIG. 26–6. Characteristics of centrifugal pumps with forward, backward and radial propellers.

Centrifugal Pump Impeller Design. Like centrifugal fan rotating elements, centrifugal pump impellers can be designed with forward, straight and backward blades.

Figure 26–6 shows the velocity diagrams of three hypothetical pump rotors, each of one blade. The discharge pressure and efficiency graphs in Figure 26–6 indicate the relative operating characteristics of complete pumps of the three types of blading.

Although the straight- and the forward-blade pumps have very stable discharge pressure characteristics, the efficiency of both of these types is relatively low when compared with the backward type blade.

Most centrifugal pumps are designed with some variation of the backward blade, since their efficiency is so much better than that of competing types. As indicated in the several graphs shown, considerable change in the operating characteristics can be obtained by changes in the blade design. This diversity of resultant effects is of considerable value in designing pumps for special applications.

AIR-LIFT PUMPS

Air-lift pumps are low in price and simple in operation. They are not efficient as power users.

In the typical air-lift installation one riser discharge main and one supply air line are within the well casing. The main is supplied with a flared inlet at the bottom and the air line passing down the well hole inside the casing and outside of the discharge riser is turned up at the bottom and discharged within the main.

In operation the compressed air passes into the riser main deep below the water level of the well and produces a mixture of air bubbles and water. This mixture of air and water is much lighter in weight than the water on the outside of the riser; thus the movement of the mixture is upward under the pressure of the water and downward on the outside of the riser. The height to which this type of pumping system will operate is dependent upon the amount of submergence at the point where the air is discharged into the riser and the amount of air pressure available to assist in moving the water upward.

Air-lift pumps operate at approximately 30% power efficiency, although theoretically they can reach 50%. The air lift does adapt itself, however, to applications where other types of pumping equipment are not so usable. Further, for certain classes of water the de-aeration effect of the pumping process of the air lift is very beneficial.

Air lifts adapt themselves to handling hot liquids, sandy, colloidal and corrosive waters and for emergency pumping installations where more complicated pumping equipment is not to be had. It also has found some use in pumping water from drilled wells too crooked for deep-well centrifugal or beam-operated plunger pump installations.

INJECTORS

In its simplest form the injector consists of at least four parts. There must be the steam nozzle to deliver the steam to the injector at a high velocity. A combining tube must take the steam from the nozzle and mix this steam with the water that is to be forced into the boiler. To make the best use of energy available, a delivery tube must receive this mixture and assist in converting the velocity into a pressure to force the water against the boiler pressure. An overflow must be provided, as supplementary to the three parts just mentioned, to take care of the excess water that the injector cannot utilize.

How an Injector Operates. In operation the combining tube receives its steam from the steam nozzle at a very high velocity (see Figure 26–7). The action of the high-velocity steam is to drive out by ejection the air in the chamber about the combining tube, which air it immediately condenses. The condensing of steam reduces its volume several hundred times. This, then, forms more vacuum and pulls in more water. Thus the process is continuous.

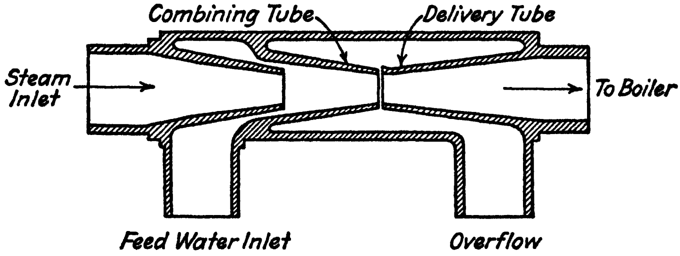


FIG. 26–7. Cross section of a simple injector.

As the high-velocity steam is condensed it imparts its velocity head to the entrained water in the condensing or combining tube and the mixture passes at a very high velocity to the delivery tube. The delivery tube is tapered down to a small diameter, and as the water passes through this small section it reaches its highest velocity. The tube then diverges, or gets larger, and the velocity head changes to a pressure head and forces the water on through the check valve and into the boiler.

Should the proportion of steam and hot water not be just right, so that some of the water spills over in the process of combining, the excess will pass out through the overflow valve to the drain. The combining tube must function as a jet condenser and as a suction pump at the same time. Two things are then required of the combining tube: it must successfully condense steam; and it must produce a partial vacuum.

The best condensing water is cold water. The lower the temperature of the water used in condensing, the better will be the vacuum. The coldest water available is most desirable for the successful operation of the injector. Since the colder the water available for the injector, the greater will be the vacuum produced in the injector; and the greater the vacuum, the greater the distance the injector will lift the water by suction; it then follows that the colder the water available, the greater is the suction lift. High lifts require colder water than low lifts. In other words, if the steam pressure is kept constant, the injector will lift water over greater heads as the temperature of the water is lowered.

Automatic Injectors. If by jolts, vibration of parts, or changes of pressure the injector should stop delivering water, with the simple injector it would be necessary to start again by hand manipulation. Many injectors, however, are equipped to adjust themselves to this condition automatically (see Figure 26-8). The devices that make this possible are usually sliding collars or nozzles that immediately adjust themselves to the change of pressures, permitting some of the water to

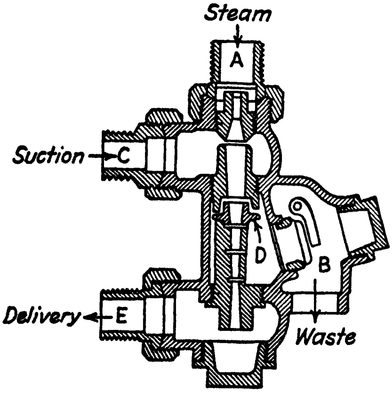


FIG. 26-8. Sectional view of automatic injector.

pass to the overflow to keep the injector cool. This automatic feature gives this type of injector the classification of automatic injector.

STEAM-JET PUMPS

To the engineer the steam-jet pump is the modified form of the injector known also as the ejector. The principle of operation is the same as that of the simple injector; that is, the steam enters through a nozzle at a high velocity and discharges into a combining tube. This combining tube is connected to the water supply to be pumped.

The velocity of the steam carries the water and the condensed steam into the delivery tube, the condensation of the steam creating a partial vacuum in the combining tube and pulling in more water to the ejector.

The ejector will handle muddy and gritty water with but little difficulty, as there are no moving parts. The grit will, of course, soon wear the tubes of the pump.

The limitations of the ejector correspond to those of the injector. Under short lifts it will deliver water to high points, but under high lifts it will not deliver the water as high. If we approach the practical maximum lift of 24 ft. it will deliver against a head of 30 to 50 ft., whereas under a lift of 3 to 6 ft. it will deliver water against a head of 100 to 150 ft.

Like all equipment working under partial vacuum conditions. it will not lift water that is too near to the boiling point.

WATER-JET PUMPS

Under favorable conditions a water-jet pump can be used to lift water from low points if sufficient head of water is available to do the pumping. When a low water pressure is available, only very limited lifts can be accomplished. With sufficient head, lifts up to 24 ft. can be installed.

THE PULSOMETER

For handling large quantities of water over short periods of the year, especially water containing much silt and foreign matter, and for portable operation in mines, excavations and basements the pulsometer can be economically applied.

Its over-all efficiency compares well with that of the cheaper reciprocating pumps, and its cost and weight are less.

It will lift water by suction under the best conditions from 20 to 25 ft. but, like the reciprocating pump, works much better on lifts of less than 15 ft.

ROTARY PUMPS

Rotary pumps have a very extensive application for pumping oil for industrial presses, oil burners and similar factory jobs where a positive pressure is essential and where the pumped fluid is free from grit and solids. Rotary pumps have been extensively used as boosters of a city water supply for either fire or industrial applications. They have the advantage of being self-priming and can be used for different and varying discharge pressures as required in skyscrapers and manufacturing plants built on hillside locations. Rotary pumps can be classified as drum, gear and roller type. The drum pump is most suitable for highly viscous fluids, the gear and roller types being more extensively used for free-flowing fluids of low viscosity.

In the rotary pump the rotation of the moving parts actually squeezes the fluid or liquor out into the discharge line with as positive an action as a piston pump.

WATER PUMPING DATA

1 U. S. gallon = 231 cubic inches.
1 U. S. gallon = 3.785 liters.
1 U. S. gallon = 0.833 British Imperial gallons.
1 acre foot = 325,851 U. S. gallons.
1 second foot = 1 cubic foot of water per second.
1 pound pressure per square inch = 2.31 feet vertical head of water.
1 ounce pressure = 1.732 inches of water.
1 inch of water = 0.577 ounces.
1 inch of water = 0.036 pounds.
1 inch of mercury = 1.133 feet of water.
1 atmosphere = 29.92 inches mercury.
1 atmosphere = 14.7 pounds per square inch.
1 atmosphere = 33.9 feet of water.
1 cubic foot of ice = 57½ pounds.
1 foot of water head = 62.42 pounds pressure per square foot.
1 foot of water head = 0.434 pounds per square inch.
1 foot of water head = 0.0295 atmosphere.
1 foot of water head = 0.882 inches mercury.

Theoretical pump horsepower

$$= \frac{\text{U. S. gallons per min.} \times \text{head in ft.} \times \text{specific gravity}}{3960}.$$

Brake horsepower of pump

$$= \frac{\text{U. S. gallons per min.} \times \text{head in feet} \times \text{specific gravity}}{3960 \times \text{pump efficiency}}.$$

TABLE 26–1. WEIGHT OF WATER AT DIFFERENT TEMPERATURES

Temperature, °F.	Weight of Onc Cubic Foot of Water, lbs.	Specific Gravity
32	62.42	0.9997
40	62.43	1.0000
50	62.42	0.9997
60	62.37	0.9990
70	62.30	0.9979
80	62.22	0.9966
90	62.11	0.9949
100	62.00	0.9931
110	61.86	0.9909
120	61.71	0.9886
130	61.55	0.9860
140	61.38	0.9832
150	61.20	0.9803
160	61.00	0.9772
170	60.80	0.9739
180	60.58	0.9704
190	60.36	0.9668
200	60.12	0.9631
210	59.90	0.9592
220	59.63	0.9552
230	59.37	0.9510
240	59.11	0.9468
250	58.83	0.9425
260	58.55	0.9379
270	58.26	0.9332
280	57.96	0.9284
290	57.65	0.9234
300	57.33	0.9183
310	57.00	0.9130
320	56.66	0.9075
330	56.30	0.9019
340	55.94	0.8961
350	55.57	0.8902

TABLE 26-2. SPECIFIC GRAVITY OF SOME LIQUIDS
(Temperature 40° Fahrenheit)

Substance	Specific Gravity
Alcohol ethyl	0.789
Alcohol methyl	0.795
Brine CaCl 28%	1.275
Brine NaCl 22%	1.171
Brine MgCl 26%	1.250
Lubricating oil	0.91
Vegetable oil	0.92
Water	1.00
Water, sea	1.025

SECTION XXVII

PIPING AND TUBING DETAILS AND DATA

In the accepted parlance of mechanical engineering, the name *pipe* is restricted to tubular products of materials and dimensions used for pipe lines and commonly manufactured in iron pipe sizes. The *outside* diameter of all wrought iron and steel pipe is the same for all weights for a given pipe size because of the necessity of making pipe dies and screw fittings of one uniform standard of threads. Pipe is nominally designated by its inside diameter, but since its outside diameter for any one size of pipe must remain fixed because of the fixed inside diameter of the collets of thread-cutting equipment, the changes that take place on account of increased pipe weight are made on the inside diameter. Thus a "standard pipe" of nominal 1 in. diameter is larger on the inside than an "extra heavy pipe" of 1 in. diameter. A schedule 40 pipe of nominal 1½ in. diameter is larger on the inside than a schedule 80 pipe of nominal 1½ in. diameter.

The name tube or tubing is given more latitude in definition but in most instances it refers to a welded or seamless tubular manufacture of a specified outside diameter. This outside diameter in the United States is generally the decimal equivalent by eighths of an inch or a multiple thereof.

Of the most common pipe materials, steel predominates. For many years wrought iron was the favorite and is still used extensively where corrosion is a serious problem. For mains above the ground and in most water distribution systems not in the ground there is but little preference between wrought iron and steel.

Cast iron is used almost entirely for underground water and drainage systems and gives excellent service. Water mains of wrought iron and steel are used in underground installations only when the work is very temporary, or where the first cost is more important than long life. Cast iron resists corrosion much better than wrought iron or steel.

TABLE 27–1. STANDARD AND EXTRA HEAVY PIPE DIMENSIONS

Commercial Size	External Diameter	Internal Diameter of Standard	Internal Diameter of Extra Heavy	Weight per Ft. Standard	Weight per Ft. Extra Heavy
⅛	0.405	0.269	0.215	0.244	0.314
¼	0.540	0.364	0.302	0.424	0.535
⅜	0.675	0.493	0.423	0.567	0.738
½	0.840	0.622	0.546	0.850	1.08
¾	1.05	0.82	0.742	1.13	1.47
1	1.31	1.04	0.957	1.67	2.17
1¼	1.66	1.38	1.278	2.27	2.99
1½	1.90	1.61	1.50	2.71	3.63
2	2.37	2.07	1.93	3.65	5.02
2½	2.87	2.46	2.32	5.79	7.66
3	3.50	3.06	2.90	7.57	10.2
3½	4	3.54	3.36	9.10	12.5
4	4.5	4.02	3.82	10.7	15.0
4½	5	4.5	4.29	12.54	17.6
5	5.56	5.04	4.81	14.6	20.7
6	6.625	6.06	5.76	19	28.5
7	7.625	7.02	6.625	23.5	38.0
8	8.625	7.98	7.625	28.5	43.4
9	9.625	8.94	8.625	33.9	48.7
10	10.625	10.0	9.75	40.4	54.7
11	11.75	11.0	10.75	45.5	60.0
12	12.75	12.00	11.75	49.56	65.4

TABLE 27–2. DOUBLE EXTRA STRONG PIPE

Nominal Pipe Size, in.	Outside Diameter, in.	Nominal Wall Thickness		Weight per Ft., Plain Ends, lbs. per lin. ft.
		Wrought Iron, in.	Steel, in.	
½	0.840	0.307	0.294	1.714
¾	1.050	0.318	0.308	2.440
1	1.315	0.369	0.358	3.659
1¼	1.660	0.393	0.382	5.214
1½	1.900	0.411	0.400	6.408
2	2.375	0.447	0.436	9.029
2½	2.875	0.565	0.552	13.695
3	3.500	0.615	0.600	18.583
4	4.500	0.690	0.674	27.541
5	5.563	0.768	0.750	38.552
6	6.625	0.884	0.864	53.160
8	8.625	0.895	0.875	72.424

In the selection of pipe for brine-tank cooling coils wrought iron is usually preferred as a more corrosion resistant material for brine service. If wrought-iron pipe is used for the coils, the submerged headers and fittings should likewise be of the same materials to keep electrolytic action to a minimum.

Until recent years steel and wrought-iron pipe were sold as "standard," "extra heavy" and "double extra heavy." As operating pressures were increased in many of the processing fields, these classifications were found to be inadequate and a system of *schedule numbers* was adopted.

At the present time, pipe is handled under both the old and the new classifications. For the information of the user, *Schedule 40* of the new classification corresponds to "standard weight" of the old. *Schedule 80* corresponds to extra-heavy pipe.

Table 27–1 gives the dimensions and weights of the "standard" and "extra heavy" pipe up to 12 in. Above 12 in. in diameter, iron and steel pipe are sold on an outside diameter classification.

TABLE 27–3. DIMENSIONS OF WELDED AND SEAMLESS STEEL PIPE

Nominal Pipe Size	Outside Diameter	Nominal Wall Thicknesses for Schedule Numbers									
		Schedule 10	Schedule 20	Schedule 30	Schedule 40	Schedule 60	Schedule 80	Schedule 100	Schedule 120	Schedule 140	Schedule 160
⅛	0.405	...		...	**0.068**		**0.095**	...	...	...	...
¼	0.540	...	...	...	**0.088**	...	**0.119**	...	...	...	...
⅜	0.675	...	...	...	**0.091**		**0.126**	...	...	...	
½	0.840	...	...	...	**0.109**		**0.147**	...		...	0.187
¾	1.050	...	...	...	**0.113**	...	**0.154**	...	...	...	0.218
1	1.315	...	...	...	**0.133**	...	**0.179**	...	...	...	0.250
1¼	1.660	...	...	...	**0.140**		**0.191**	...	...	...	0.250
1½	1.900	...	...	...	**0.145**	...	**0.200**	...	...	...	0.281
2	2.375	...	...	...	**0.154**	...	**0.218**	...	...	...	0.343
2½	2.875	...	...	...	**0.203**		**0.276**	...	...	...	0.375
3	3.5	...	...	...	**0.216**	...	**0.300**	...	...	...	0.437
3½	4.0	...	...	...	**0.226**	...	**0.318**	...	...	...	...
4	4.5	...	...	...	**0.237**	...	**0.337**	...	0.437	...	0.531
5	5.563	...	...	...	**0.258**	...	**0.375**	...	0.500	...	0.625
6	6.625	...	...	...	**0.280**	...	**0.432**	...	0.562	...	0.718
8	8.625	...	0.250	**0.277**	**0.322**	**0.406**	**0.500**	0.593	0.718	0.812	0.906
10	10.75	...	0.250	**0.307**	**0.365**	**0.500**	**0.593**	0.718	0.843	1.000	1.125
12	12.75	...	0.250	**0.330**	**0.406**	**0.562**	**0.687**	0.843	1.000	1.125	1.312
14 O.D.	14.0	0.250	0.312	**0.375**	0.437	0.593	0.750	0.937	1.062	1.250	1.406
16 O.D.	16.0	0.250	0.312	**0.375**	0.500	0.656	0.843	1.031	1.218	1.437	1.562
18 O.D.	18.0	0.250	0.312	0.437	0.562	0.718	0.937	1.156	1.343	1.562	1.750
20 O.D.	20.0	0.250	0.375	0.500	0.593	0.812	1.031	1.250	1.500	1.750	1.937
24 O.D.	24.0	0.250	0.375	0.562	0.687	0.937	1.218	1.500	1.750	2.062	2.312
30 O.D.	30.0	0.312	0.500	0.625	...	...	...	...	...	...	...

All dimensions are given in inches.

The decimal thicknesses listed for the respective pipe sizes represent their nominal or average wall dimensions. For tolerances on wall thickness, see appropriate material specification.

Thicknesses shown in bold face type in Schedules 30 and 40 are identical with thicknesses for "standard weight" pipe in former lists; those in Schedules 60 and 80 are identical with thicknesses for "extra strong" pipe in former lists.

The Schedule Numbers indicate approximate values of the expression 1000 × P/S.

Table 27–3 gives the dimensions of welded and seamless steel pipe, and Table 27–4 gives the dimensions of welded wrought-iron pipe for the new schedule classifications. Table 27–5 and Table 27–6 give the nominal weights of welded and seamless steel pipe, and welded wrought iron pipe, respectively. These are taken from the American Standards Association Bulletin B36-10-1939 which is recommended to designers of piping layouts.

TABLE 27–4. DIMENSIONS OF WELDED WROUGHT-IRON PIPE

Nominal Pipe Size	Outside Diameter	Nominal Wall Thicknesses for Schedule Numbers					
		Schedule 10	Schedule 20	Schedule 30	Schedule 40	Schedule 60	Schedule 80
⅛	0.405	.....	....	.....	**0.070**	.....	**0.098**
¼	0.540	.....	....	.....	**0.090**	.....	**0.122**
⅜	0.675	.....	....	....	**0.093**	.....	**0.129**
½	0.840	....	.....	.....	**0.111**	.....	**0.151**
¾	1.050	.....	.....	....	**0.115**	.....	**0.157**
1	1.315	.....	....	....	**0.136**	.....	**0.183**
1¼	1.660	....	....	....	**0.143**	.....	**0.195**
1½	1.900	....	.....	.....	**0.148**	.....	**0.204**
2	2.375	....	.....	....	**0.158**	....	**0.223**
2½	2.875	.....	....	....	**0.208**	....	**0.282**
3	3.5	.....	.....	.....	**0.221**	.....	**0.306**
3½	4.0	.....	.....	.....	**0.231**	.....	**0.325**
4	4.5	.....	....	.....	**0.242**	.....	**0.344**
5	5.563	.....	.....	.....	**0.263**	....	**0.383**
6	6.625	.....	.....	.....	**0.286**	.....	**0.441**
8	8.625	.....	.....	**0.283**	**0.329**	.....	**0.510**
10	10.75	....	....	**0.313**	**0.372**	**0.510**	0.606
12	12.75	.....	....	**0.336**	0.414	0.574	0.702
14 O.D.	14.0	0.250	0.312	0.375	0.437	0.625	0.750
16 O.D.	16.0	0.250	0.312	0.375	0.500	0.687	.....
18 O.D.	18.0	0.250	0.312	0.437	0.562	0.750	.....
20 O.D.	20.0	....	0.375	0.500	0.562	.....	.....

All dimensions are given in inches.

The decimal thicknesses listed for the respective pipe sizes represent their nominal or average wall dimensions. For tolerances on wall thickness, see appropriate material specification.

Thicknesses shown in bold face type in Schedules 30 and 40 are identical with thicknesses for "standard weight" pipe in former lists; those in Schedules 60 and 80 are identical with thicknesses for "extra strong" pipe in former lists.

The Schedule Numbers indicate approximate values of the expression $1000 \times P/S$.

For the installation of a complete welded system, butt-welding fittings are available in standard dimensions from most suppliers. The American Standards Association standards for 180° return bends are given in Table 27-8 and for tees and elbows in Table 27-7.

TABLE 27-5. NOMINAL WEIGHTS OF WELDED AND SEAMLESS STEEL PIPE *

Nominal Pipe Size, in.	Sch. 10	Sch. 20	Schedule 30		Schedule 40		Sch. 60	Sch. 80	Sch. 100	Sch. 120	Sch. 140	Sch. 160
	Plain Ends	Plain Ends	Plain Ends	Threads and Couplings	Plain Ends	Threads and Couplings	Plain Ends	Plain Ends	Plain Ends	Plain Ends	Plain Ends	Plain Ends
⅛					**0.25**	**0.25**		**0.32**				
¼					**0.43**	**0.43**		**0.54**				
⅜					**0.57**	**0.57**		**0.74**				
½					**0.86**	**0.86**		**1.09**				1.31
¾				....	**1.14**	**1.14**		**1.48**				1.94
1				....	**1.68**	**1.69**		**2.18**				2.85
1¼					**2.28**	**2.29**		**3.00**				3.77
1½					**2.72**	**2.74**		**3.64**				4.86
2			...		**3.66**	**3.68**		**5.03**				7.45
2½					**5.80**	**5.82**		**7.67**				10.0
3					**7.58**	**7.62**		**10.3**		....		14.3
3½					**0.11**	**9.21**		**12.5**		.....		....
4					**10.8**	**10.9**	...	**15.0**		19.0		22.6
5					**14.7**	**14.9**		**20.8**		27.1		33.0
6					**19.0**	**19.2**		**28.6**		36.4		45.3
8		22.4	24.7	**25.0**	28.6	28.8	35.7	43.4	50.9	60.7	67.8	74.7
10		28.1	34.3	**35.0**	40.5	41.2	54.8	64.4	77.0	89.2	105	116
12		33.4	43.8	**45.0**	53.6	55.0	73.2	88.6	108	126	140	161
14 O.D.	36.8	45.7	54.6	....	63.3		85.0	107	131	147	171	190
16 O.D.	42.1	52.3	62.6		82.8		108	137	165	193	224	241
18 O.D.	47.4	59.0	82.0		105		133	171	208	239	275	304
20 O.D.	52.8	78.6	105		123		167	209	251	297	342	374
24 O.D.	63.5	94.7	141		171		231	297	361	416	484	536
30 O.D.	99.0	158	197									

*** Weights are given in pounds per linear foot and are for pipe with plain ends except for sizes which are commercially available with threads and couplings for which both weights are listed.**

Weights shown in bold face type in Schedules 30 and 40 are identical with weights for "standard weight" pipe in former lists, those in Schedules 60 and 80 are identical with weights for "extra strong" pipe in former lists.

The Schedule Numbers indicate approximate values of the expression 1000 × P/S.

TABLE 27-6. NOMINAL WEIGHTS OF WELDED WROUGHT-IRON PIPE *

Nominal Pipe Size, in.	Schedule 10	Schedule 20	Schedule 30		Schedule 40		Schedule 60	Schedule 80
	Plain Ends	Plain Ends	Plain Ends	Threads and Couplings	Plain Ends	Threads and Couplings	Plain Ends	Plain Ends
1/8	....	..	.	....	**0.25**	**0.25**	.....	**0.32**
1/4	...	...	.	..	**0.43**	**0.43**	.....	**0.54**
3/8	....	.		. .	**0.57**	**0.57**	.. .	**0.74**
1/2	....	.. .		.	**0.86**	**0.86**	... .	**1.09**
3/4	. .	.. .		.. .	**1.14**	**1.14**	.....	**1.48**
1	.. .	.		.	**1.68**	**1.69**	.....	**2.18**
1¼	. ..	..	. .	.	**2.28**	**2.29**	. ..	**3.00**
1½	....	.		.	**2.72**	**2.74**	. ...	**3.64**
2	....	.			**3.66**	**3.68**	.. .	**5.03**
2½	..				**5.80**	**5.82**	...	**7.67**
3	.. .	..		..	**7.58**	**7.62**	... .	**10.3**
3½	....	.	.	..	**9.11**	**9.21**	. ..	**12.5**
4	.. .	. .	.	...	**10.8**	**10.9**	....	**15.0**
5	....	. .		....	**14.7**	**14.9**	.....	**20.8**
6	....	. .		....	**19.0**	**19.2**	.....	**28.6**
8	....	. .	**24.7**	**25.0**	**28.6**	**28.8**	.....	**43.4**
10	...	. .	**34.3**	**35.0**	**40.5**	**41.2**	**54.8**	64.4
12	.	..	**43.8**	**45.0**	53.6	55.0	73.2	88.6
14 O.D.	36.0	44.8	53.6	....	62.2	.....	87.6	104
16 O.D.	41.3	51.4	61.4	....	81.2	.....	111	.....
18 O.D.	46.5	57.9	80.5	....	103	. .	136	.
20 O.D.	...	77.0	103	.	115	.	.. ..	......

* Weights are given in pounds per linear foot and are for pipe with plain ends except for sizes which are commercially available with threads and couplings for which both weights are listed.

Weights shown in bold face type in Schedules 30 and 40 are identical with weights for "standard weight" pipe in former lists; those in Schedules 60 and 80 are identical with weights for "extra strong" pipe in former lists.

The Schedule Numbers indicate approximate values of the expression 1000 × P/S.

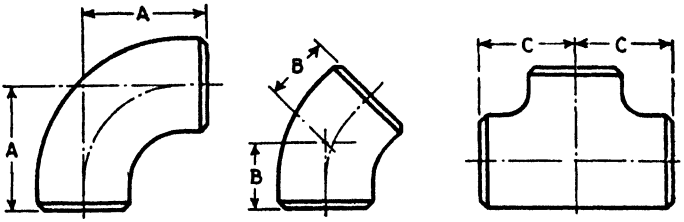


TABLE 27–7. DIMENSIONS OF BUTT-WELDING ELBOWS AND TEES *

Nominal Pipe Size	Outside Diameter at Bevel	Center-to-end		
		90° Welding Elbows A	45° Welding Elbows B	Of Run, Welding Tee C
1	1.315	1½	⅞	1½
1¼	1.660	1⅞	1	1⅞
1½	1.900	2¼	1⅛	2¼
2	2.375	3	1⅜	2½
2½	2.875	3¾	1¾	3
3	3.500	4½	2	3⅜
3½	4.000	5¼	2¼	3¾
4	4.500	6	2½	4⅛
5	5.563	7½	3⅛	4⅞
6	6.625	9	3¾	5⅝
8	8.625	12	5	7
10	10.750	15	6¼	8½
12	12.750	18	7½	10

All dimensions given in inches.

* The dimensions of welding tees cover those which have branch outlets from one size less than half the size of the runway opening of the tees to full size.

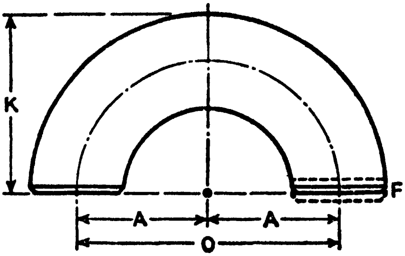


TABLE 27-8. DIMENSIONS OF BUTT-WELDING 180-DEG. RETURN BENDS

Nominal Pipe Size	Outside Diameter at Bevel	Center-to-center	Back to Face
1	1.315	3	2 3/16
1¼	1.660	3¾	2¾
1½	1.900	4½	3¼
2	2.375	6	4 3/16
2½	2.875	7½	5 3/16
3	3.500	9	6¼
3½	4.000	10½	7¼
4	4.500	12	8¼
5	5.563	15	10 5/16
6	6.625	18	12 5/16
8	8.625	24	16 5/16
10	10.750	30	20⅜
12	12.750	36	24⅜

All dimensions given in inches.

Pipe Threads. Threaded pipe is rapidly giving way to welded construction in the piping for refrigeration. By the welding torch, emergency connections can be made readily without the use of many fittings. However, there are a number of parts of any system that are more conveniently connected by threaded fittings than by a welded connection.

During the past decade more attention has been given to the improvement of pipe threads for pressure work. The adopted standard specifications of the American Standards Association for form of threads, pitch, taper and length of thread is given herewith. For more complete information on pipe threads the American Standards Association Bulletin B2-1-1945 is recommended. A partial abstract from the bulletin on pipe threads is as follows:

PIPE THREADS

1. *Form of Thread.* The angle between the sides of the thread is 60 deg when measured in an axial plane and the line bisecting this angle is perpendicular to the axis. The depth of the sharp *V* thread, *H*, is

$$H = 0.8660p$$

The basic maximum depth of the truncated thread is based on factors entering into the manufacture of cutting tools and the making of tight joints.

$$h = 0.800p$$

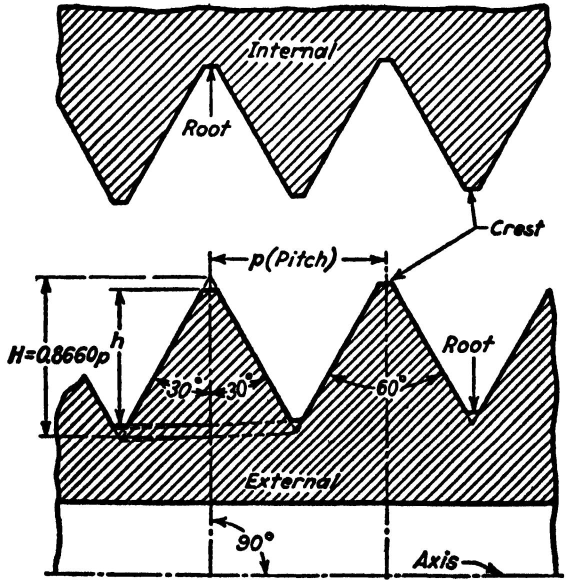
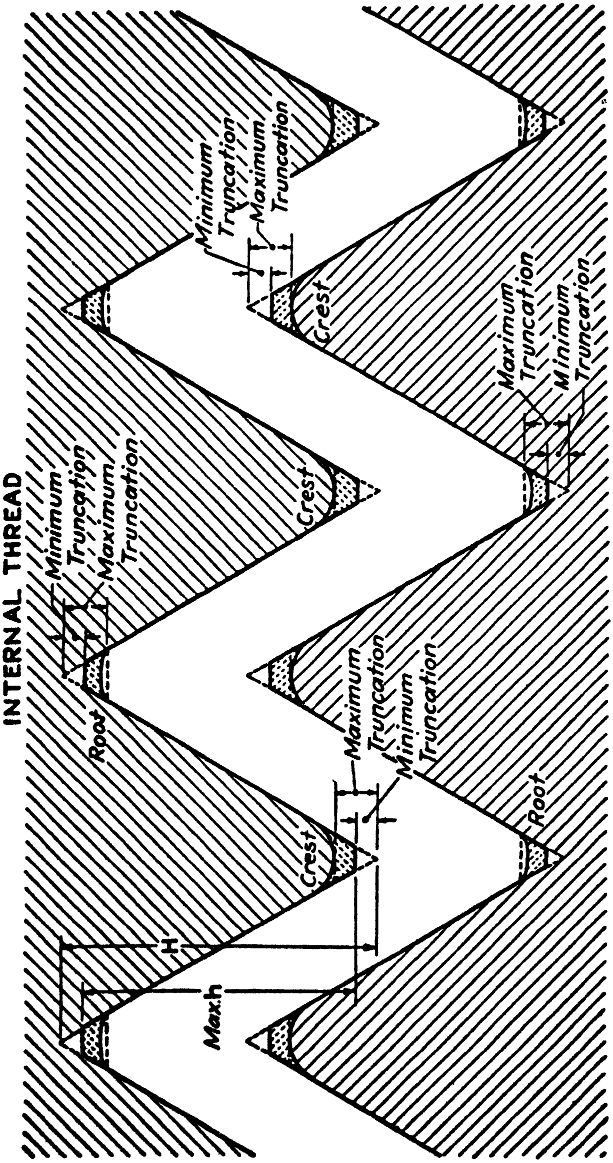


FIG. 27-1. Basic form of American standard taper pipe thread.

2. *The crest and root of pipe threads are truncated a minimum of 0.033p.* The maximum depth of truncation for the crest and root of these pipe threads will be found in Table 27-9.

The sketches at the head of Table 27-9, giving a sectional view of this standard thread form, represent the truncated thread form by a straight line. However, when closely examined, the crest and roots of commercially manufactured pipe threads appear slightly rounded and it is intended that the pipe threads of product shall be acceptable when crest and root of the tools or chasers lie within the limits set up in Table 27-9.



Pipe thread design features to accompany Table 27-9.

TABLE 27-9. LIMITS ON CREST AND ROOT OF AMERICAN STANDARD EXTERNAL AND INTERNAL TAPER PIPE THREADS

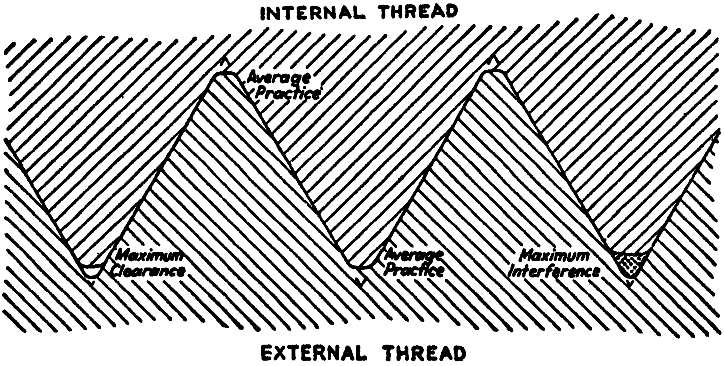
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Threads per In.	Depth Sharp V Thread H, in.	Depth Pipe Thread h		Truncation				Tolerance on Truncation, in.	Equivalent Width of Flat				Tolerance on Equiv. Width of Flat, in.
				Minimum		Maximum			Minimum		Maximum		
		Maximum, in.	Minimum, in.	Formula	In.	Formula	In.		Formula	In.	Formula	In.	
27	0.03208	0.02963	0.02496	0.033p	0.0012	0.096p	0.0036	0.0024	0.038p	0.0014	0.111p	0.0041	0.0027
18	0.04811	0.04444	0.03833	0.033p	0.0018	0.088p	0.0049	0.0031	0.038p	0.0021	0.102p	0.0057	0.0036
14	0.06186	0.05714	0.05071	0.033p	0.0024	0.078p	0.0056	0.0032	0.038p	0.0027	0.090p	0.0064	0.0037
11½	0.07531	0.06957	0.06261	0.033p	0.0029	0.073p	0.0063	0.0034	0.038p	0.0033	0.084p	0.0073	0.0040
8	0.10825	0.10000	0.09275	0.033p	0.0041	0.062p	0.0078	0.0037	0.038p	0.0048	0.072p	0.0090	0.0042

The basic dimensions of the American Standard taper pipe thread are given in inches to four and five decimal places. While this implies a greater degree of precision than is ordinarily attained, these dimensions are so expressed for the purpose of eliminating errors in computations.

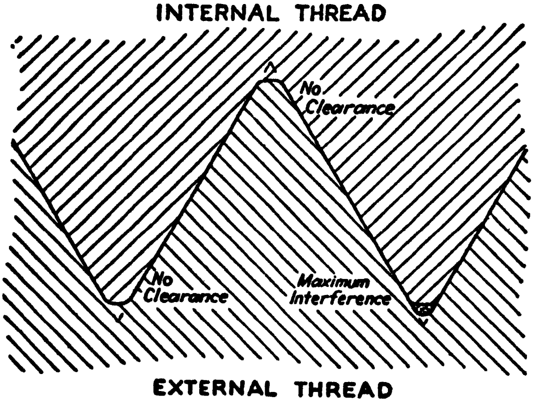
3. *Pitch.* The pitch is the distance from a point on a screw thread to a corresponding point on the next thread measured parallel to the axis.

$$\text{Pitch in inches } (p) = \frac{1}{\text{Threads per inch } (n)}$$

4. *Taper of Thread.* The taper of the thread is 1 in 16 or 0.75 in. per ft. measured on the diameter and along the axis.



American Standard Taper Pipe Thread for Pressure-Tight Joints



American Standard Dryseal Taper Pipe Threads for Pressure-Tight Joints

FIG. 27–2.

5. *Diameter of Thread.* The basic pitch diameters of the taper thread are determined by the following formulas based on the outside diameter of the pipe and the pitch of the thread:

$$E_0 = D - (0.050D + 1.1)\frac{1}{n}$$

$$E_1 = E_0 + 0.0625L_1$$

where

D = basic outside diameter of pipe,
E_0 = pitch diameter of thread at end of pipe,
E_1 = pitch diameter of thread at the gaging notch or large end of internal thread,
L_1 = normal engagement by hand between external and internal threads.

6. *Length of Thread.* The basic length of the effective external taper thread, L_2, is determined by the following formula based on the outside diameter of the pipe and the pitch of the thread:

$$L_2 = (0.80D + 6.8)\frac{1}{n}$$

where

D = basic outside diameter of pipe.

This formula determines directly the length of effective thread which includes two usable threads slightly imperfect at the crest.

7. *Engagement Between External and Internal Taper Threads.* The normal length of engagement between external and internal taper threads when screwed together by hand is shown in Column 6, Table 27–10. This length is controlled by the construction and use of the gages. It is recognized that in special applications, such as flanges for high pressure work, longer thread engagement is used, in which case the pitch diameter is maintained and the pitch diameter E_0 at the end of pipe is proportionately smaller.

The normal type of joint made with American Standard Pipe Thread is that employing an external taper and an internal taper thread.

Copper water tubing is classified by letter identification for three common applications. Type K classification is used for general plumbing and underground services. Type L is for general plumbing only and Type M is for soldered connections and fittings.

Types K and L may be furnished in either the annealed or hard-drawn condition. When furnished in coils they are annealed after coiling, but when furnished in straight lengths they may be either annealed or hard drawn. Type M is furnished only in straight lengths and hard drawn.

Copper tubing is tested up to a unit pressure of 1000 lbs. per sq. in. in the standard tubing formula:

$$p = \frac{2t \times 6000}{\text{O.D.}} = \frac{12{,}000t}{\text{O.D.}},$$

where

p = pressure in pounds per square inch.
t = wall thickness in inches.
O.D. = outside diameter of the tube in inches.

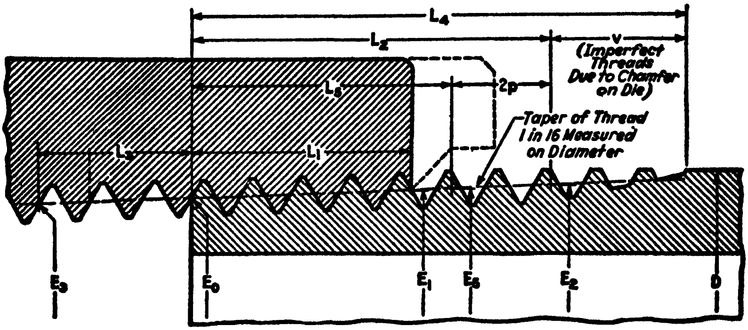

L4
L2
V
(Imperfect Threads Due to Chamfer on Die)
L5
2p
Taper of Thread 1 in 16 Measured on Diameter
L3
L1
E3
E0
E1
E5
E2
D

TABLE 27-10. BASIC DIMENSIONS, AMERICAN STANDARD TAPER PIPE THREAD *

1	2	3	4	5	6	7	8	9	10	11
Nominal Pipe Size	Outside Diameter of Pipe D	Threads per Inch n	Pitch of Thread p	Pitch Diameter at Beginning of External Thread E_0	Hand-tight Engagement			Effective Thread, External		
					Length L_1		Diameter E_1	Length L_2		Diameter E_2
					In.	Threads		In.	Threads	In.
1/16	0.3125	27	0.03704	0.27118	0.160	4.32	0.28118	0.2611	7.05	0.28750
⅛	0.405	27	0.03704	0.36351	0.180	4.86	0.37476	0.2639	7.12	0.38000
¼	0.540	18	0.05556	0.47739	0.200	3.60	0.48089	0.4018	7.23	0.50250
⅜	0.675	18	0.05556	0.61201	0.240	4.32	0.62701	0.4078	7.34	0.63750
½	0.840	14	0.07143	0.75843	0.320	4.48	0.77843	0.5337	7.47	0.79179
¾	1.050	14	0.07143	0.96768	0.339	4.75	0.98887	0.5457	7.64	1.00179
1	1.315	11½	0.08696	1.21363	0.400	4.60	1.23863	0.6828	7.85	1.25630
1¼	1.660	11½	0.08696	1.55713	0.420	4.83	1.58338	0.7068	8.13	1.60130
1½	1.900	11½	0.08696	1.79609	0.420	4.83	1.82234	0.7235	8.32	1.84130
2	2.375	11½	0.08696	2.26902	0.436	5.01	2.29627	0.7565	8.70	2.31630
2½	2.875	8	0.12500	2.71953	0.682	5.46	2.76216	1.1375	9.10	2.79062
3	3.500	8	0.12500	3.34062	0.766	6.13	3.38850	1.2000	9.60	3.41562
3½	4.000	8	0.12500	3.83750	0.821	6.57	3.88881	1.2500	10.00	3.91562
4	4.500	8	0.12500	4.33438	0.844	6.75	4.38712	1.3000	10.40	4.41562
5	5.563	8	0.12500	5.39073	0.937	7.50	5.44929	1.4063	11.25	5.47862
6	6.625	8	0.12500	6.44609	0.958	7.66	6.50597	1.5125	12.10	6.54062
8	8.625	8	0.12500	8.43359	1.063	8.50	8.50003	1.7125	13.70	8.54062
10	10.750	8	0.12500	10.54531	1.210	9.68	10.62094	1.9250	15.40	10.66562
12	12.750	8	0.12500	12.53281	1.360	10.88	12.61781	2.1250	17.00	12.66562
14 O.D.	14.000	8	0.12500	13.77500	1.562	12.50	13.87262	2.2500	18.90	13.91562
16 O.D.	16.000	8	0.12500	15.76250	1.812	14.50	15.87575	2.4500	19.60	15.91562
18 O.D.	18.000	8	0.12500	17.75000	2.000	16.00	17.87500	2.6500	21.20	17.91562
20 O.D.	20.000	8	0.12500	19.73750	2.125	17.00	19.87031	2.8500	22.80	19.91562
24 O.D.	24.000	8	0.12500	23.71250	2.375	19.00	23.86094	3.2500	26.00	23.91562

All dimensions are given in inches.

* The basic dimensions of the American Standard Taper Pipe Thread are given in inches to four or five decimal places. While this implies a greater degree of precision than is ordinarily attained, these dimensions are the basis of gage dimensions and are so expressed for the purpose of eliminating errors in computations.

The standard dimensions, weights, tolerances and wall thickness of the different types of copper tubing are given in Table 27-11:

TABLE 27-11. DIMENSIONS, WEIGHTS AND TOLERANCES FOR COPPER WATER TUBES

(All tolerances in this table are plus and minus except as otherwise indicated)

Standard Water Tube Size, in.	Actual Outside Diameter, in.	Average Outside Diameter		Wall Thickness, inches						Theoretical Weight, lb. per ft.		
		Tolerance, in.		Type K		Type L		Type M		Type K	Type L	Type M
		Annealed	Drawn	Nominal	Tolerance	Nominal	Tolerance	Nominal	Tolerance			
⅛	0.250	0.002	0.001	0.032	0.003	0.025	0.0025	0.025	0.0025	0.085	0.068	0.068
¼	0.375	0.002	0.001	0.032	0.004	0.030	0.0035	0.025	0.0025	0.134	0.126	0.107
⅜	0.500	0.0025	0.001	0.049	0.004	0.035	0.0035	0.025	0.0025	0.269	0.198	0.145
½	0.625	0.0025	0.001	0.049	0.004	0.040	0.0035	0.028	0.0025	0.344	0.285	0.204
⅝	0.750	0.0025	0.001	0.049	0.004	0.042	0.0035	0.030	0.0025	0.418	0.362	0.263
¾	0.875	0.003	0.001	0.065	0.0045	0.045	0.004	0.032	0.003	0.641	0.455	0.328
1	1.125	0.0035	0.0015	0.065	0.0045	0.050	0.004	0.035	0.0035	0.839	0.655	0.465
1¼	1.375	0.004	0.0015	0.065	0.0045	0.055	0.0045	0.042	0.0035	1.04	0.884	0.682
1½	1.625	0.0045	0.002	0.072	0.005	0.060	0.0045	0.049	0.004	1.36	1.14	0.940
2	2.125	0.005	0.002	0.083	0.007	0.070	0.006	0.058	0.006	2.06	1.75	1.46
2½	2.625	0.005	0.002	0.095	0.007	0.080	0.006	0.065	0.006	2.93	2.48	2.03
3	3.125	0.005	0.002	0.109	0.007	0.090	0.007	0.072	0.006	4.00	3.33	2.68
3½	3.625	0.005	0.002	0.120	0.008	0.100	0.007	0.083	0.007	5.12	4.29	3.58
4	4.125	0.005	0.002	0.134	0.010	0.110	0.009	0.095	0.009	6.51	5.38	4.66
5	5.125	0.005	0.002	0.160	0.010	0.125	0.010	0.109	0.009	9.67	7.61	6.66
6	6.125	0.005	0.002	0.192	0.012	0.140	0.010	0.122	0.010	13.9	10.2	8.92
8	8.125	0.006	+0.002 −0.004	0.271	0.016	0.200	0.014	0.170	0.014	25.9	19.3	16.5
10	10.125	0.008	+0.002 −0.006	0.338	0.018	0.250	0.016	0.212	0.015	40.3	30.1	25.6
12	12.125	0.008	+0.002 −0.006	0.045	0.020	0.280	0.018	0.254	0.016	57.8	40.4	36.7

Note: For copper gas and oil burner tubes, the tolerances shown above for various wall thicknesses (type K) apply irrespective of diameter.

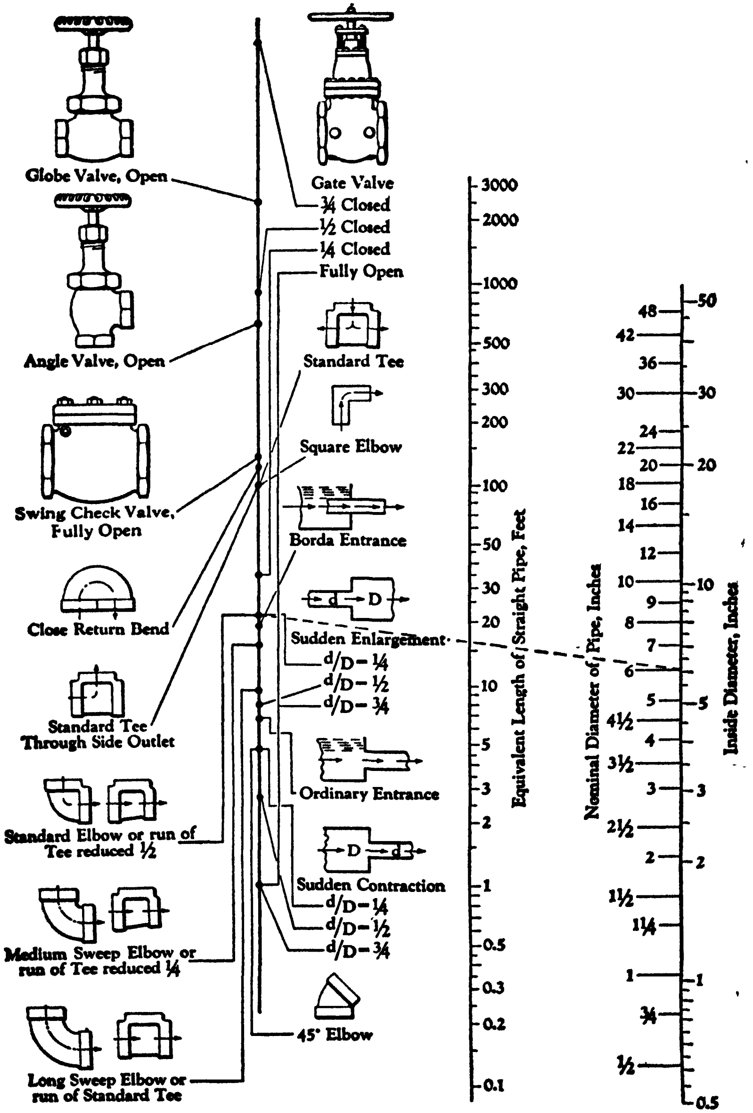
For tubes other than round no standard tolerances are established.

These tolerances do not apply to condenser and heat exchanger tubes.

The American Standard Association specification for copper water tubing is number H23.1, 1941. For purchasers of large quantities of copper tubing an examination of this specification is highly recommended.

Resistance of Valves and Fittings. In the installation of piping for refrigeration, too often the suction and discharge lines are inadequate. The failure to recognize the high loss of pressure through fittings and valves is a common error in design.

Figure 27-3 is given as a quick method of determining the loss by resistance of valves and fittings and is reproduced here by permission of Crane and Company.



(Reproduced by permission of Crane Co. Chicago, Ill.)

FIG. 27-3. Resistance of valves and fitting to flow of fluids.

The dotted line in the nomograph indicates that a 6-in. standard elbow is equivalent in resistance to approximately 16 ft. of 6-in. standard pipe.

In the diagram several examples of sudden enlargement or contraction are indicated. In using the nomograph it is designed for the smaller diameter to be selected for use on the inside diameter scale.

The loss of head in feet for fittings can be computed by the equation:

$$H = \mathrm{K}\frac{V^2}{64.4},$$

where

H = the loss of head in feet.
V = the velocity of the fluid.
K = Kappa, a coefficient for different types of fittings.

For application in this equation, Gieseke and Badgett at the University of Texas found that the coefficient value for standard ells was 0.9, for standard tees 1.8, and for 45° ells 0.42. Crane and Company tests indicated a value of 10.0 for a globe valve and 5.0 for an angle valve.

SECTION XXVIII

ACCIDENT PREVENTION AND SAFETY IN REFRIGERATION

More than one-half of industrial accidents are preventable. Eternal vigil of both the builders and users of equipment is imperative if accidents are to be reduced to a minimum.

Moving Machines. All moving machines should receive careful inspection at scheduled periods, in addition to the casual daily inspection by the operating staff.

Gears should be completely enclosed, set screws counter-sunk, belts completely guarded and open vats and wells fenced or covered. Emery wheel guards should be built of steel plate and so installed as to discourage removal of the guard. Emery wheel operation is not too safe even when all precautions are taken, but a completely steel-guarded wheel and approved grinding goggles on every operator should be required in every plant.

Crushing of the hands or feet by blocks of ice or boxes of produce is a common accident in refrigeration plants. Repeated educational talks to the operators are necessary to reduce this hazard to a minimum.

In ice plants slippery floors cause many falls and injuries. Nonslip shoes are recommended.

Severe electrical shock, often fatal, is common in carelessly managed plants. All lamp cords used on the ice pulling floors, all overhead crane cables, and all switches and electrical devices should be examined frequently. Especially where moisture and brines are spilled on the floors, fatal grounding through the human body is very possible when exposed electrical connections can be reached by the operator's hands or touched by his head.

Great care should be exercised in working with toxic refrigerants, especially in machinery rooms where there is danger of a rupture of a valve or a cylinder head. Some of the worst accidents recorded in refrigeration history have been brought about by careless or uninformed operators not understanding the hazards inherent in starting or stopping a compressor operating on a toxic refrigerant. Compressor rooms should be designed to offer every possibility of the operating force making a quick getaway if a rupture of any part of the compression system occurs.

A nonreturn valve installed in the discharge line is a very good safety precaution against the failure of a cylinder head or machine valve. Remote control stop valves on each compressor are also very desirable for the safety of the compressor room operators. Gas helmets are too often in an inconvenient place. They are a most important part of any plant using toxic refrigerants. An occasional safety drill of the compressor plant personnel is recommended. This will indicate to all concerned the location of the several safety devices and emphasize any weakness in the planned safe practice procedure.

Ice crushers have become notorious for their maiming of operators. If an ice crusher cannot be installed to be operated with safety, then its installation should be deferred until the proper safety appliances can be secured and erected.

Great care should be exercised in designing, installing, and operating refrigeration equipment. New applications and equipment are coming forward every day, and those who install and operate such machines or devices should take every precaution to see that such installations do not constitute a hazard to life and property.

Every user of refrigeration is advised to secure a copy of the complete code on mechanical refrigeration, B-9, of the American Standards Association. Copies can be secured from the American Society of Refrigerating Engineers, 40 West 40th Street, New York City. The price is 20 cents.

Sections 5, 6, 7, 9, 14 and 15 of the A.S.A. Code are given here for quick reference.

Section 5

Refrigerant Classification

Refrigerants shall, for Safety Code purposes, be divided into groups as follows:

Group 1	*Chemical Formula*
Carbon dioxide	CO_2
Dichlorodifluoromethane (Freon 12)	CCl_2F_2
Dichloromonofluoromethane (Freon 21)	$CHCl_2F$
Dichlorotetrafluoroethane (Freon 114)	$C_2Cl_2F_4$
Dichloromethane (Carrene No. 1) (Methylene chloride)	CH_2Cl_2
Trichloromonofluoromethane (Freon 11) (Carrene No. 2)	CCl_3F

	Chemical Formula
Group 2	
Ammonia	NH_3
Dichloroethylene	$C_2H_2Cl_2$
Ethyl chloride	C_2H_5Cl
Methyl chloride	CH_3Cl
Methyl formate	$HCOOCH_2$
Sulphur dioxide	SO_2
Group 3	
Butane	C_4H_{10}
Ethane	C_2H_6
Isobutane	$(CH_3)_3CH$
Propane	C_3H_8

Section 6

Institutional Occupancies

General. No Refrigerating System shall be installed in or on public stairways, hallways, lobbies, entrances or exits.

Refrigerant piping or tubing shall not be carried through floors except that, for the purpose of connecting to a condenser on the roof, it may be carried through a continuous, rigid and tight fire-resisting (four (4) hour rating) flue or shaft having no openings on intermediate floors, or it may be carried on the outer wall of the building provided it is not located in an air shaft, closed court or in other similar open spaces enclosed within the outer walls of the building.

Group 1 Refrigerants. No Refrigerating System shall be installed in any room except Unit Systems each containing not more than ten (10) pounds of a Group 1 refrigerant, and then only when a window or other ventilation is provided, and except as otherwise permitted.

Systems each containing not more than twenty (20) pounds of a Group 1 refrigerant may be installed in kitchens, laboratories, and mortuaries.

Systems each containing more than twenty (20) pounds of a Group 1 refrigerant shall be of the Indirect type with all refrigerant containing parts, excepting parts installed outside the building, installed in a machinery room, used for no other purpose and in which for Group 1 refrigerants, excepting carbon dioxide, no flame is present or apparatus to produce a flame is installed.

When a Group 1 refrigerant, other than carbon dioxide, is used in a system any portion of which is in a room where there is an apparatus for producing an open flame, then such refrigerant shall be classed in Group 2 unless the flame producing apparatus is provided with a hood and flue capable of removing the products of combustion to the open air. Flames by matches, cigarette lighters, small alcohol lamps and similar devices, shall not be considered as open flames.

Group 2 Refrigerants. Group 2 refrigerants shall not be used except in Unit Systems containing not more than six (6) pounds of refrigerant when installed in kitchens, laboratories, or mortuaries, or except in systems containing not more than five hundred (500) pounds of refrigerant and having all refrigerant containing parts installed in a Class T machinery room.

Group 2 refrigerants shall not be used in a system for air conditioning for human comfort, except in an Indirect Vented Closed Surface System, or in a Double Indirect Vented Open Spray System, or in an Indirect Absorptive Brine System.

Group 3 Refrigerants. Group 3 refrigerants shall not be used in Institutional Occupancies.

Section 7

Public Assembly Occupancies

General. No Refrigerating System shall be installed in or on public stairways, hallways, lobbies, entrances or exits.

Refrigerant piping or tubing shall not be carried through floors except from basements to the first floor or from the top floor to a penthouse or the roof, or except that for the purpose of connecting to a condenser on the roof it may be carried through a continuous, rigid and tight fire-resisting (four (4) hour rating) flue or shaft having no openings or intermediate floors, or it may be carried on the outer wall of the building provided it is not located in an air shaft, closed court or in other similar open spaces enclosed within the outer walls of the building.

Group 1 Refrigerants. The maximum quantity of a Group 1 refrigerant in a Direct System used for air conditioning for human comfort shall be limited by the volume of the space to be air conditioned as shown in the table.

A system containing more than fifty (50) pounds of a Group 1 refrigerant, other than carbon dioxide, and which includes air ducts shall be of the Indirect type unless it conforms to requirements as follows:

a. Positive automatic fire damper or dampers shall be provided to cut off the refrigerant containing apparatus from the duct system.

b. Automatic means shall be provided to close the dampers and to stop the fan when the temperature of the air in the duct at the damper location reaches 210 F. when the damper is on the discharge side of a system containing a heating coil and at 125 F. when the damper is on the suction side of the system, or on the discharge side of a system containing no heating coil.

A system containing more than one thousand (1000) pounds of a Group 1 refrigerant shall be of the Indirect type with all the refrigerant containing parts, excepting parts mounted outside the building, installed in a machinery room used for no other purpose and in which for Group 1 refrigerants, excepting carbon dioxide, no flame is present or apparatus to produce a flame is installed.

When a Group 1 refrigerant, other than carbon dioxide, is used in a system, any portion of which is in a room where there is an apparatus for producing an open flame, then such refrigerant shall be classed in Group 2 unless the flame producing apparatus is provided with a hood and flue capable of removing the products of combustion to the open air. Flames by matches, cigarette lighters, small alcohol lamps and similar devices, shall not be considered as open flames.

GROUP 1 REFRIGERANT		Maximum Quantity in Lbs. per 1000 Cu. Ft. of Air Conditioned Space *
Name	Chemical Formula	
Carbon dioxide	CO_2	12
Dichlorodifluoromethane (Freon 12)	CCl_2F_2	30
Dichloromethane (Carrene No. 1)	CH_2Cl_2	6
Dichloromonofluoromethane (Freon 21)	$CHCl_2F$	13
Dichlorotetrafluoroethane (Freon 114)	$C_2Cl_2F_4$	40
Trichloromonofluoromethane (Freon 11)	CCl_3F	35

* When the refrigerant containing parts of a system are located in one or more enclosed spaces, the cubical contents of the smallest enclosed space other than the machinery room, shall be used to determine the permissible quantity of refrigerant in the system.

When the evaporator is located in a duct system, the cubical content of the smallest enclosed space served by the duct system shall be used to determine the permissible quantity of refrigerant in the system unless the airflow to any enclosed space served by the duct system cannot be reduced below ¼ of its maximum, in which case the cubical contents of the entire space served by the duct system shall be used to determine the permissible quantity of refrigerant in the system.

Group 2 Refrigerants. Group 2 refrigerants shall not be used except in Unit Systems containing not more than twelve (12) pounds of refrigerant, or except in systems containing not more than one thousand (1000) pounds of refrigerant and having all refrigerant containing parts installed in a Class T machinery room.

Group 3 Refrigerants. Group 3 refrigerants shall not be used in Public Assembly occupancies.

Section 9

Commercial Occupancies

General. No Refrigerating System shall be installed in or on public stairways.

No Refrigerating System shall be installed in public hallways, lobbies, entrances, or exits, except Unit Systems containing not more than four (4) pounds of a refrigerant, provided free passage is not obstructed.

Refrigerant piping shall not be carried through floors except as follows:

a. It may be carried from basements to the first floor or from the top floor to a penthouse or the roof.

b. For the purpose of connecting to a condenser on the roof it may be carried through an approved, rigid and tight continuous fire-resisting flue or shaft having no openings on intermediate floors, or it may be carried on the outer wall of the building provided it is not located in an air shaft, closed court, or in other similar open spaces enclosed within the outer walls of the building.

c. In systems containing Group 1 refrigerants and used for air conditioning for human comfort, the refrigerant piping may be carried through floors provided it is enclosed in an approved, rigid and tight continuous fire-resisting flue or shaft where it passes through any intermediate space not served by the air conditioning system. The flue shall be vented to the outside or to a space served by the air conditioning system. Such systems shall conform to the requirements of paragraph 9.20.

Group 1 Refrigerants. Direct Systems containing more than twenty (20) pounds of a Group 1 refrigerant when used for air conditioning for human comfort, shall be limited by the volume of the space to be air conditioned as follows:

A system containing more than fifty (50) pounds of a Group 1 refrigerant, other than carbon dioxide, and which includes air ducts shall be of the Indirect type unless it conforms to requirements as follows:

a. Positive automatic fire damper or dampers shall be provided to cut off the refrigerant containing apparatus from the duct system.

b. Automatic means shall be provided to close the dampers and to stop the fan when the temperature of the air in the duct at the damper location reaches 210 F. when the damper is on the discharge side of a system containing a heating coil and at 125 F. when the damper is on the suction side of the system or on the discharge side of a system containing no heating coil.

A system containing more than one thousand (1000) pounds of a Group 1 refrigerant shall be of the Indirect type with all the refrigerant containing parts, excepting parts mounted outside the building, installed in a machinery room used for no other purpose and in which for Group 1 refrigerants, excepting carbon dioxide, no flame is present or apparatus to produce a flame is installed.

Group 2 Refrigerants. A system containing more than twenty (20) pounds of a Group 2 refrigerant shall not be used for air conditioning for human comfort unless it is of the Indirect Vented Closed Surface, Double Indirect Vented Open Spray, Indirect Absorptive Brine, or primary circuit of a Double Refrigerant type with all the refrigerant containing parts, excepting parts mounted outside the building, installed in a machinery room used for no other purpose.

Any system containing more than six hundred (600) pounds of a Group 2 refrigerant shall have all refrigerant containing parts installed in a Class T machinery room.

Group 3 Refrigerants. Group 3 refrigerants shall not be used except in a Unit System containing not more than six (6) pounds of refrigerant.

Section 14

Tests

General. Every refrigerant containing part of every system shall be tested and proved tight by the manufacturer at not less than the minimum test pressures shown in Table 28–1.

Every refrigerant containing part of every system that is erected on the premises, except compressors, safety devices, pressure gages, and control mechanisms, that are factory tested, shall be tested and proved tight after complete installation and before operation at not less than the minimum pressures shown in Table 28-1.

Test Medium. No oxygen or any combustible gas or combustible mixture of gases shall be used for testing.

TABLE 28-1. TEST PRESSURES

Refrigerant		Min. Test Pressure, lbs. per sq. in.	
Name	Chemical Formula	High Pressure Side	Low Pressure Side
Ammonia	NH_3	300	150
Butane	C_4H_{10}	90	50
Carbon dioxide	CO_2	1500	1000
Dichlorodifluoromethane (Freon 12)	CCl_2F_2	235	145
Dichlorotetrafluoroethane (Freon 114)	$C_2Cl_2F_4$	80	50
Dichloromethane (Carrene No. 1) (Methylene chloride)	CH_2Cl_2	30	30
Dichloromonofluoromethane (Freon 21)	$CHCl_2F$	70	50
Dichloroethylene	$C_2H_2Cl_2$	30	30
Ethane	C_2H_6	1100	600
Ethyl chloride	C_2H_5Cl	60	50
Isobutane	$(CH_3)_3CH$	130	75
Methyl chloride	CH_3Cl	215	125
Methyl formate	$HCOOCH_3$	50	50
Propane	C_3H_8	325	210
Sulphur dioxide	SO_2	170	95
Trichloromonofluoromethane (Freon 11)	CCl_3F	50	50

Refrigerants Not Listed. For refrigerants not listed in Table 28-1, the test pressure for the high pressure side shall be not less than the saturated vapor pressure of the refrigerant at 150 F. The test pressure for the low pressure side shall be not less than the saturated vapor pressure of the refrigerant at 115 F. In no case shall the test pressure be less than thirty (30) pounds per square inch by gage.

Posting of Tests. A dated declaration of test, signed by the installer, shall be mounted in a frame, protected by glass, and posted in the machinery room. If an inspector is present at the tests he shall also sign the declaration.

Section 15

Instructions

User's Responsibility. All Refrigerating Systems shall be maintained in a cleanly manner, free from accumulations of oily dirt, waste, and other debris, and shall be kept readily accessible at all times.

Instructions. It shall be the duty of the person in charge of the premises on which a Refrigerating System containing more than twenty (20) pounds of refrigerant is installed, to place a card conspicuously as near as practicable to the refrigerant condensing unit giving directions for the operation of the system, including precautions to be observed in case of a breakdown or leak as follows:

a. Instructions for shutting down the system in case of emergency.

b. The name, address and day and night telephone numbers for obtaining service.

c. The name, address and telephone number of the municipal inspection department having jurisdiction and instructions to notify said department immediately in case of emergency.

Signs. Each Refrigerating System shall be provided with an easily legible metal sign permanently attached and easily accessible, indicating thereon the name and address of the manufacturer or installer, the kind and total number of pounds of refrigerant contained in the system, and the field test pressure applied.

Systems containing more than one hundred (100) pounds of refrigerant should be provided with metal signs having letters of not less than one-half (½) inch in height designating the main shut-off valves to each vessel, main steam or electrical control, remote control switch, and pressure limiting device. On all exposed high pressure and low pressure piping in each room where installed outside the machinery room, shall be signs as above with the name of the refrigerant and the letters HP or LP.

Marking. Each separately sold refrigerant containing vessel larger than five (5) cubic feet in gross volume, each refrigerant condensing unit, and each refrigerant compressor shall carry a nameplate marked with the manufacturer's name and address, identification number, and name of refrigerant used.

Helmets. One mask or helmet shall be required where amount of Group 2 refrigerants between one hundred (100) and one thousand (1000) pounds, inclusive, are employed. If more than one thousand (1000) pounds of Group 2 refrigerants are employed, at least two masks or helmets shall be required.

Only complete helmets or masks marked as approved by the Bureau of Mines of the United States Department of the Interior and suitable for the refrigerant employed shall be used and they shall be kept in a suitable cabinet immediately outside the machinery room or other approved accessible location.

Canisters or cartridges of helmets or masks shall be renewed immediately after having been used or the seal broken and if unused, must be renewed at least once every two (2) years. The date of filling shall be marked thereon.

Refrigerant Storage. Not more than three hundred (300) pounds of refrigerant in approved containers shall be stored in a machinery room.

No refrigerant shall be stored in a room in which less than twenty (20) pounds are used in the system.

Refrigerants on the user's premises in excess of that permitted in the machinery room shall be stored in a fireproof shed or room used for no other purpose.

Charging and Discharging Refrigerants. When refrigerant is added to a system, except a Unit System containing not more than six (6) pounds of refrigerant, it shall be charged into the low pressure side of the system. No container shall be left connected to a system except while charging or withdrawing refrigerant.

Refrigerants withdrawn from Refrigerating Systems shall only be transferred to approved containers. No refrigerant shall be discharged to a sewer.

The containers from which refrigerants are discharged into or withdrawn from a Refrigerating System must be carefully weighed each time they are used for this purpose, and the containers must not be filled in excess of the permissible filling weight for such containers and such refrigerants as are prescribed in the Interstate Commerce Commission's "Regulations for the Transportation by Rail of Explosives and other Dangerous Articles in Freight, Express and Baggage Services including Specifications for Shipping

Containers," effective October 1, 1930, with supplements 1 to 18 inclusive.

SAFETY INSTRUCTIONS FOR ICE AND COLD STORAGE PLANT OPERATION *

Plant Operation:

(a) Combustible materials should not be kept in the plant and in every case should be kept well away from liquid ammonia receivers.

(b) Good ventilators capable of rapid air changes should be in compressor room.

(c) Apply belt dressing only to that part of belt leaving a pulley. Liquid belt dressing applied with a long handle brush is much safer than stick belt dressing.

(d) Water or oil leakage from stuffing boxes should not be allowed to accumulate around equipment.

(e) All electrical equipment shall be grounded.

(f) Switchboards:

  (1) All switchboards should be of marble or slate, or other nonconductible material.

  (2) Current-carrying parts shall be enclosed with insulating material or grounded metal casings, so arranged to prevent accidental contact and to prevent short circuits.

  (3) A rubber mat or insulated platform shall be placed on floor in front of switchboard and extending its entire length.

  (4) No energized conductors or busses shall be touched or handled except by an authorized employee who wears properly tested rubber gloves.

  (5) Entrances to rear of switchboard shall be enclosed with gates. Warning signs forbidding entrance of unauthorized persons shall be placed on gates.

  (6) Meters or operating devices requiring attention under ordinary operating conditions every twenty-four hours, or less, must be located in the above enclosure.

(g) More than one exit is necessary for quick escape in case of emergency.

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* From *Safety Manual, for Ice and Cold Storage Industry*, Texas Employers' Insurance Association; by permission.

(h) A master disconnect switch should be located in such manner that it can be pulled without entering building. When this switch is pulled it should stop every piece of apparatus in the plant in emergencies.

(i) Oil, gasoline, or other gaseous liquids, should not be used for cleaning purposes. Use carbon tetrachloride, Stoddard Solvent, or other special cleaning fluid. Do not use carbon tetrachloride in close or unventilated places.

(j) Scaffolds should be constructed to carry a center load of three times the maximum weight of men and material expected to be placed on it.

(k) If possible, eliminate necessity of employees crossing street to read meters.

(l) Fire Prevention:

  (1) Store all inflammable liquids in either an approved oil house, in a fire-proof room, or in fire-proof cabinets.

  (2) All tanks, containers and cans shall be marked in some distinguishing manner, and are to be labeled as to contents.

  (3) Never permit anyone to smoke, use open flames, or strike sparks where inflammable liquids are used or stored.

  (4) Keep all oily rags and waste in approved metal containers.

(m) When natural gas leaks are suspected, apply a solution of soap and water to the exterior of the pipes and fittings with a brush. The soap suds will form bubbles at the point of the leak. Keep all flames, sparks, or lighted cigarettes, cigars and pipes away.

(n) On electric hand tools, an extra wire to ground the tool casing should be used. Use only approved and inspected extension cord.

(o) Air compressor tanks should be drained once a week during heavy season.

Guards:

(a) The following machines, or machine parts shall be adequately guarded (see your insurance carrier for proper guards and/or State Standards):

  (1) Belts, chains, rope drives.

  (2) Friction drives, gears, sprockets.

  (3) Vertical, inclined, or horizontal shafting.

  (4) Fly wheels, clutches, couplings, projecting shaft ends.
  (5) Emery wheels, motors or generators with exposed terminals; reciprocating machines, ice scoring machines, ice crushing machines.

Repairs or Installations:

(a) Whenever it becomes necessary to work on any engine, pump generator, motor, belting, shafting, or other piece of machinery, a warning card—DANGER—MEN WORKING—must be properly attached to the governor, valve, throttle, switch, or other device used to set the machinery in motion.
(b) Machinery shall not be worked on or repaired while in motion.
(c) When working on or in crankcase of compressors make sure that employees, tools, extension cords or other impediments are clear before turning fly wheel.
(d) Employees moving heavy equipment on rollers should not wear gloves and rollers should be of sufficient length to extend well past the skids. (A glove finger may be caught under roller and hand pulled under.)

Tools:

(a) Select the right tool for the job—never use a makeshift.
(b) Ice Tongs:

  (1) Boston type tongs are recommended for general use; 13-in. size for platform and delivery service and 14½-in. size for car icing and heavy vault service.
  (2) Tongs should have a stop rivet to prevent grips closing on hands.
  (3) Center rivets should be replaced or tongs discarded if points offset more than ½ in. to ¾ in. when closed.
  (4) Tongs shall not be carried open in hands nor hooked over shoulder.
  (5) Keep rough edges filed off points, but not too thin, as there is danger of cutting through ice. Points shall be filed on the outside only and should be kept sharp.

(c) Ice Picks.

  (1) Picks shall not be left lying around on floor. A corkboard or other soft board shall be fastened to wall, or other convenient place, where picks may be stuck when not in use.

(2) Picks shall not be carried in pockets. A scabbard shall be used.
(3) "Advertising" picks should not be used on docks or in delivery service.
(4) Picks should be kept pointed and sharp.

(d) Employees when sawing ice with hand saw should stand well to one side so that saw will not strike legs.
(e) Supervisors shall not permit the use of improper or unsafe tools or devices.
(f) All chisels, bars, drills, etc., which are held by one man and struck with a sledge hammer by another shall be held with long-handled tongs, a piece of garden, steam hose or other suitable device to prevent a glancing blow or a missed blow striking the employee holding the tool. The device used to hold the tool or bar should be at least 18 inches long, and it should be held near the outer end. The holder shall wear goggles, and also, if possible, he should protect his face.
(g) Tools should be kept on tool boards, tool racks or in tool boxes when not in use.
(h) Pike poles when not in use shall be stored on a rack or other storage provided for that purpose; they are not to be left lying around on platforms.
(i) Select wrenches of the right size for the job. Face the jaws of an adjustable wrench in the direction of pull.
(j) All edged or pointed tools shall be kept sharp. Dull tools are more dangerous than sharp ones.
(k) Avoid using a hammer with hardened face on a highly tempered tool such as a drill, file, die, jig, etc. Chips may fly.
(l) Never use a wrench on moving machinery; stop the machine.
(m) Never use an extension on a wrench. The proper length of a wrench handle is calculated by its manufacturer for the strength of the wrench jaws.

Ladders:

(a) Employees shall not be permitted to use a ladder that has cracked or broken rungs, side pieces or straps.
(b) Permanent ladders on towers, tanks, or where subject to water shall be of metal, or rungs shall be strapped to rails with metal plates. The plates or straps should be in one continuous piece.
(c) Straight ladders shall be of sufficient length that work may be reached when standing on third or fourth rung from top.

(d) Step ladders over five feet in height shall be of sufficient length that work may be reached when standing on second or third step from the top.
(e) Distance from the foot of the ladder to the wall shall not exceed one fourth of the distance from the top of ladder to floor.
(f) Ladders greater than five feet in length shall be blocked, anchored, or held by an assistant. All ladders should have nonslip shoes.
(g) Improvised ladders such as barrels, boxes, chairs, tables, etc., shall not be used.
(h) All stairways leading to the top of treating tanks, ammonia condensers, cooling towers or platforms shall be properly railed.

Safety Devices and Equipment:

(a) Gas Masks:

  (1) Every plant employee shall be instructed in the use of the ammonia gas mask. He should work in the mask periodically to become accustomed to its use.
  (2) One extra canister for the ammonia gas mask must be kept on hand at all times. Spare canisters last for an indefinite period if the cork and seal have never been removed. Replace any canister which has become rusted.
  (3) In addition to using an ammonia gas mask when shutting off valves or otherwise stopping ammonia leaks, mask must be worn by operator when making any opening in the ammonia system. Masks shall be kept in cases in a cool and convenient location. Place as near as possible to an outlet of a room. Upon attaching ammonia canisters to gas masks, the seat at the bottom must be removed. Canisters should be replaced every two years whether mask has been used or not.
  (4) When using an ammonia mask, if the odor of the gas becomes objectionable, the employee should immediately leave the gas area. He should replace the canister and examine the mask for defects before reentering.
  (5) Mask should be placed in kit so that the fabric is not creased, the tube kinked, or valve bent.

(b) Goggles:

  (1) Employees using emery wheels or portable grinders shall wear goggles equipped with shatter-proof glass.

They should be used at all times when chipping or cutting concrete, breaking up junk, porcelain, handling, demolishing or cleaning brickwork, and on all classes of material or fluids affording possibilities of injury to the eyes.

(2) Goggles of suitably colored glass shall be used when working with an acetylene torch or electric welder, and in any other places where eyes are exposed to excessive heat or glare.

(c) Rubber gloves with gauntlet protectors must be kept in an easily accessible place and used if necessary to pull cut-outs or do other electrical work.

Suitable Clothing:

(a) Loose clothing should not be worn around moving machinery. Jumpers should be kept within overalls; keep sleeves down. Loose sleeves or trouser legs are also a hazard around machinery.
(b) Do not wear inflammable articles such as celluloid cap visors, celluloid eye glass frames, oily clothing, etc.
(c) Gloves shall not be worn around moving machinery.
(d) Avoid wearing metal articles, such as rings, watch or key chains, or metal cap visors.
(e) Keep good soles on shoes at all times. Shoes with thin soles will cause bruises and blisters and will allow the penetration of nails.
(f) Employees should wear safety shoes with safety toe caps. When working on icy or slippery surfaces, shoes with a special nonslip sole should be worn.

Other American Standards Association safety practice bulletins that are of special interest to refrigeration engineers are given below. These are available at the office of the American Standards Association, 70 East 45th Street, New York City.

Short Title	*A.S.A. Number*
Abrasive Wheels	B7
Blower and Exhaust Systems	Z33.1
Building Exits Code	A9.1
National Electrical Safety Code (B.F.U. 70)	C1
Elevators, Dumbwaiters and Escalators	A17.1
Refrigerators Using Gas Fuel	Z21.19
Identification of Piping Systems, Scheme of	A13
Ladders, Safety Code	A14

"Safe Practice" pamphlets are available from National Safety Council, 20 North Wacker Drive, Chicago, Ill., on:

Short Title	*N.S.C. Number*
Safe Operation of Steam Boilers	3
Compressed Air Machinery	47
Cranes, Overhead Traveling	4
Goggles	14
Power Transmission	5 to 10 inclusive.

SAFETY IN DESIGN

The designer of each machine should incorporate safeguarding devices right into the machine. Too many machines must be provided with safety devices after they come from the manufacturer. It is very difficult to make satisfactory safety devices for a machine after it has been built.

Designers should visualize their design to see whether there is any part of their handiwork wherein an operator or repairman can be maimed for life by the crushing of a hand or finger in the moving parts which he must handle or repair frequently while the machine is in motion.

The temperature of bearings must be determined frequently, packing must be taken up and belts aligned. Provision should be made to do this with a minimum of hazard.

Projections from a machine may trip the operator. Ample aisle space should be provided so that there is no crowding of the machine operators into the danger zones.

Piping should be so designed that the expansion of the mains causes no undue strain at the compressors, condensers or evaporators. Very serious accidents have been caused by the rupture of a line or a valve at a point where the expansion pressure of the pipe has not been relieved by suitable provision of some kind.

The National Industrial Conference Board have issued "First Aid Suggestions" to their subscribers. Some of those of special interest to the refrigeration trade are given herewith.

FIRST AID SUGGESTIONS

Treatment of Burns from Scalds, Fire, Electricity. Do not open blisters. Apply burn ointment, 3% bicarbonate of soda (baking soda) in vaseline, or cover burned area with sterile gauze wet with warm saline solution (teaspoonful of salt to 1 pint of water).

Apply several thicknesses of clean gauze and bandage lightly. Send for doctor.

Treatment of Acid Burns. Thoroughly flush all parts with water. Place under shower bath if necessary. Remove acid-soaked clothes. After acid has been thoroughly washed off, dry and apply burn ointment, 3% bicarbonate of soda in vaseline. Cover burned area with plenty of sterile gauze and bandage lightly.

Treatment of Alkaline Burns (such as those from lime, plaster, potash, ammonia, etc.). Thoroughly flush all parts with water to remove all further damage from the alkali. Place under a shower bath if necessary. After alkali has been thoroughly washed off, flood the part with a mixture of equal parts of vinegar and water and apply gauze dressings; bandage lightly and send for doctor. See eye treatment, below.

Treatment of Eye Injuries. No attempt should be made to remove a foreign body stuck in the eye. In case of foreign body in, or injury to, the eye, apply a compress gauze dressing, and bandage. In acid burns, wash freely with water and follow with 3% solution of bicarbonate of soda. In alkaline burns, lime, plaster, potash, ammonia, etc., flush with a mixture of granulated sugar and water. Send to doctor at once.

Treatment of Unconscious Patients (Any Cause). Place in comfortable position, flat on back, face to one side; keep warm. Watch for vomiting. If he vomits, be careful that no foreign material enters the lungs. Loosen all tight clothing. Do not give anything to drink. Call the doctor.

Treatment for Suffocation, Electric Shock, Drowning, Gas Poisoning. Apply prone-pressure or Schäfer method of artificial respiration.

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